AFFIDAVIT

State of Michigan

County of Saginaw

Douglas M. Schuller having been sworn states that if called as a witness he can competently testify to facts stated in the affidavit based upon his own knowledge or, where stated upon information and belief, and that he believes the facts stated to be true.

1. I am employed by Delphi Steering Systems, Saginaw Michigan as Supervisor-Advanced Supplier Quality. Formerly I was Sensor Group Supervisor/Engineering for Delphi Steering Systems.

2. Delphi Steering Systems manufactures and sells steering columns to automotive customers. Included in certain Delphi manufactured steering columns is a part designated as the E-Steer Sensor (Sensor).

3 Delphi outsourced the manufacture of the sensor for the Epsilon vehicle program to Furukawa. Delphi specified the sensor performance requirements to Furukawa. Thereafter, Furukawa designed and built sensors that were provided to Delphi with the understanding that the sensors would meet Delphi's performance requirements.

4 Delphi engineers performed product validation tests of the sensors provided to Delphi by Furukawa for test purposes. The slip rings of provided sensors had solid gold plating. The product validation testing and other technical evaluations done as part of the production part approval process (PPAP), led to the purchase of sensors from Furukawa for installation in saleable steering columns.

5 Subsequent to the product validation testing and performance approval, Furukawa changed from a pure gold slip ring plating to a gold plating design which included a PTFE (polytetrafluoroethylene, commonly referred to as Teflon) additive. The material change was made without the knowledge and engineering consent of Delphi.

6. Furukawa knew that it was obligated to submit a Supplier Change Review Request (SCRR) to Delphi before it altered the slip ring plating. This is evidenced by the fact that it had submitted such requests for other unrelated changes to this Sensor during its established business relationship with Delphi. Please see the attached Exhibit A-1.

7. Furukawa provided Sensors to Delphi which were intended for installation into steering columns for sale to its customer. It was unknown to Delphi that these Sensors included the PTFE additive.

8. On December 12, 2002, Furukawa initiated a proposal to Delphi pertaining to a Furukawa-proposed change in the plating (this is now known to be the change to include

the PTFE additive). See Exhibit A. Furukawa provided some initial data regarding this proposal, and in March, 2003 it was agreed that a change could eventually be made "PROVIDED" the necessary testing and approval process was successfully completed. (Furukawa Exhibit 1). The testing mandated in the Halstead letter (Furukawa Exhibit 1) did not occur, and no final approval was provided by Delphi to Furukawa. This testing and approval did not happen, and Delphi did not ever indicate to Furukawa that such final approval had been obtained. In fact, through two subsequent face-to-face meetings in Saginaw, Michigan between the key Furukawa and Delphi engineering representatives, it was made clear to Furukawa that Delphi had ultimately REJECTED the proposal to change the plating for the Epsilon E-Steer sensor. The primary objections to the proposal, as stated at the time, were the specific concern for electrical performance due to potential contaminating affects of PTFE, and also the fact that it was too late to introduce sufficient system-level and vehicle-level testing for such a significant change. This proposal was rejected during a September 17, 2003 face-to-face meeting. At this time, Furukawa did not disclose that saleable sensors already in customer vehicles included the PTFE. Furukawa had repeated opportunities to make this disclosure over a nine month period subsequent to their initial proposal, including the two face-to-face meetings, but instead chose to continue to build and deliver "saleable" sensors which included the PTFE.

9. The steering columns failed during routine and regular use by vehicle owners. During the months following the September 17, 2003 meeting, Delphi reported to Furukawa that there were repeated steering column failures related to the sensor. Delphi and Furukawa jointly performed analysis of a number of sensors which had been returned from customer vehicles and were confirmed to exhibit electrical noise resulting from the slip ring interface within the sensors.

10. In parallel to analysis performed by Delphi and Furukawa, Delphi employed the services of an outside laboratory, Deringer Ney, to perform analysis on a failed sensor returned by General Motors from a customer vehicle. The initial test report from Deringer Ney, dated January 23, 2004, provided the first evidence to Delphi that the PTFE additive had been included in sensors sold by Delphi to its customer. Delphi Response Exhibit E.

11. The specific presence of PTFE can only be detected by sophisticated chemical analysis, including electron microscopic analysis. Before providing this evidence to Furukawa, Delphi engineering personnel immediately asked Furukawa by phone whether PTFE was included in "saleable" sensors; Furukawa did not disclose the use of PTFE. Then, on January 24, 2004, Delphi engineering personnel forwarded the Deringer Ney findings to Furukawa. Furukawa stated that key management representatives would immediately fly from Japan to Saginaw, Michigan for a meeting.

12. On January 28, 2004 Furukawa representatives from Japan traveled to Saginaw, Michigan. At this time, they acknowledged, with deep apologetic gesture, that PTFE had been added to the "saleable" sensors. During the time Delphi and Furukawa were doing exhaustive testing to determine the cause or causes of the steering column failures,

Furukawa had not disclosed that PTFE had been included in all "saleable" sensors shipped to Delphi from and after December 17, 2002.

13. On April 8, 2004, Furukawa submitted a "5-phase Problem-Solving Report." (Delphi Response Exhibit B). This document states Furukawa's reasons for not disclosing the presence of PTFE in the "saleable" sensors. The report stated: "Since Furukawa did not have expertise/knowledge of plating, we did not refer to the details including composition. We did not activate the formal change process due to lack of knowledge." Further, Furukawa's report stated, "In December, 2002, when the plating characteristic was discussed between Delphi and Furukawa again, we realized the necessity of the authorization. But is was difficult at that time to bring up the history and fact because it was after the implementation."

14. In my engineering judgment, the sensors failed primarily because the PTFE caused an insufficient gold plating process. Subsequent chemical analysis showed that the gold layer was not consistently applied, and in fact an extremely high amount of tiny voids existed where gold should have been adhered to the substrate. In these voids, chemical analysis showed the presence, among other elements, of Nickel and Fluorine (Fluorine being a major element of the compound PTFE). The PTFE, which upon further disclosure by Furukawa had actually been mixed with the Nickel in a previous manufacturing operation, had prevented the appropriate adhesion of the gold. In fact, the electron microscope images provided by Deringer Ney confirmed that gold adhesion was not consistent. In addition, particles which had apparently worn from the slip rings and included many elements, including Fluorine, could be found in excess quantity on the tips of the brushes. The brushes are intended to make direct contact with the gold to transmit electrical signals. Some or all of the 18 wires that form the two brushes for each slip ring circuit did not make the intended electrical contact with the slip ring. PTFE particulate can act as an insulator between one or more wires, or the required electrical current may not pass if the gold plating is absent. The underlying nickel is not a suitable or approved electrical conductor. These factors provided an insufficient electrical interface of the slip rings within the mechanical operating environment of the sensor.

Douglas M. Schuller

Subscribed and sworn to before me

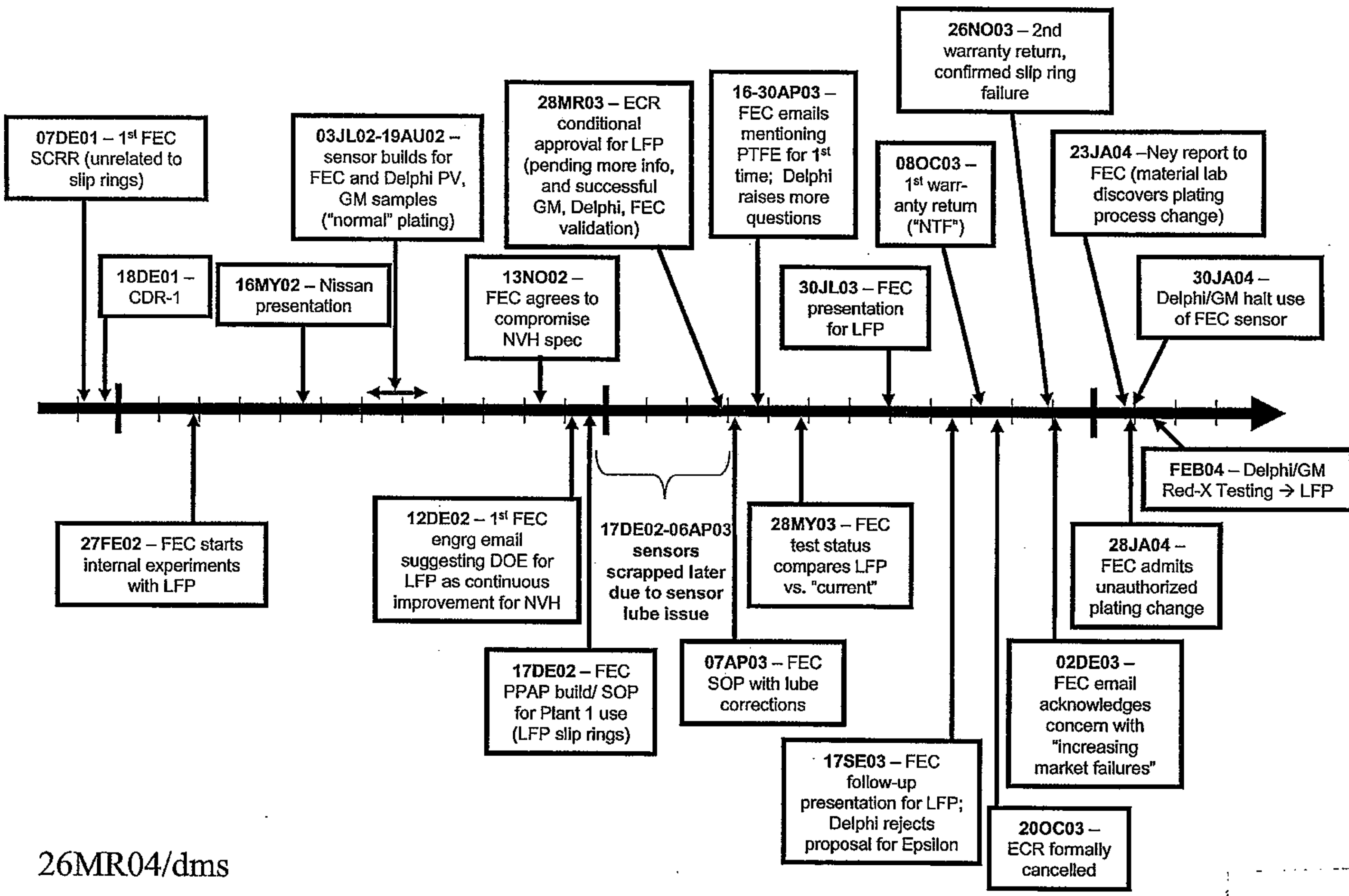
On 6/29 ,2007
Paula Dils
Notary Public
Saginaw County Michigan
My Commission expires April 22, 2012

PAULA DILS
NOTARY PUBLIC-STATE OF MICHIGAN
COUNTY OF SAGINAW COUNTY
My Commission Expires APRIL 22, 2012
Acting in the County of Saginaw

Paula Dils

Epsilon E-Steer Sensor

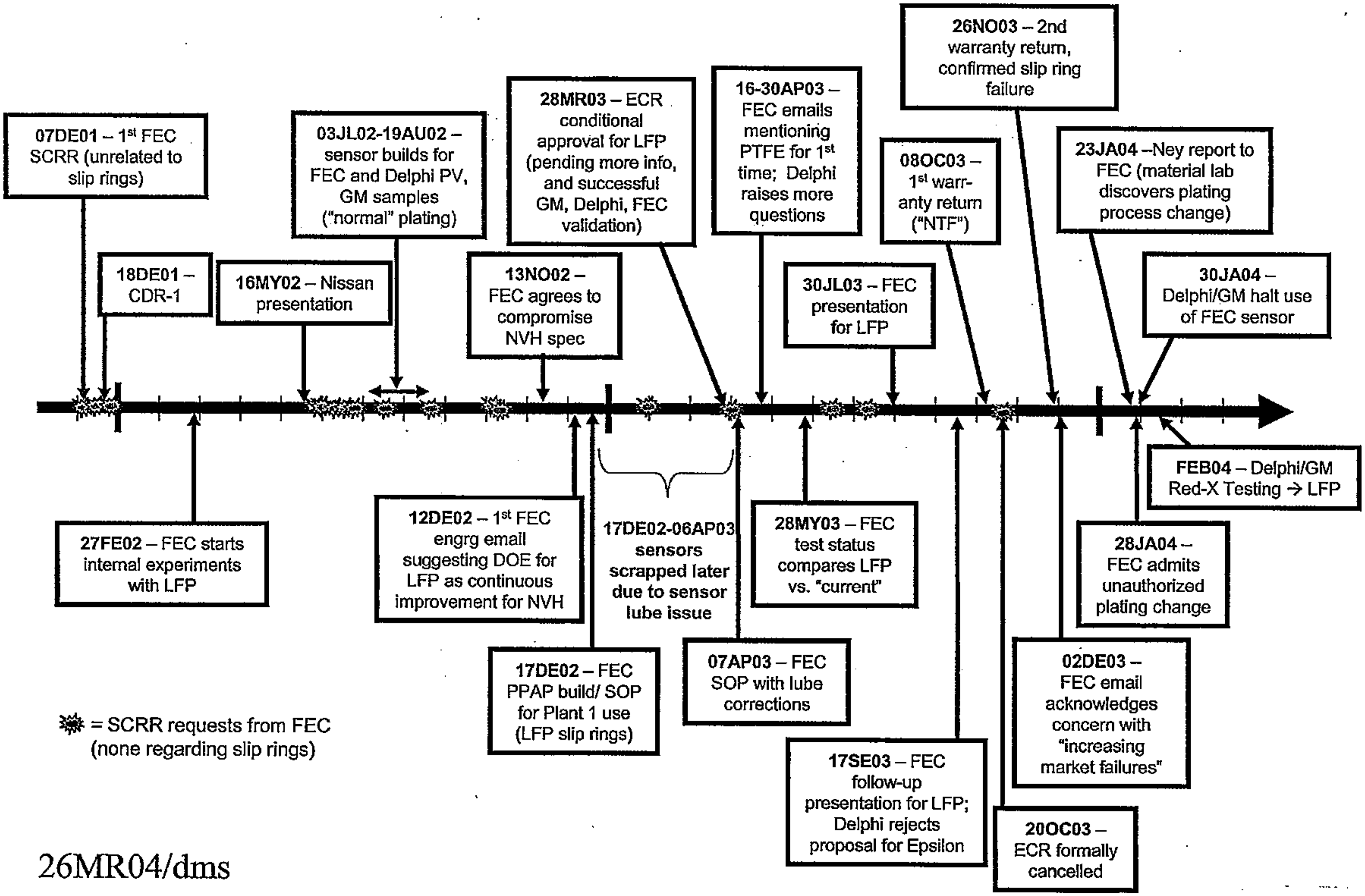
History of Furukawa Slip Ring Plating Change



26MR04/dms

EXHIBIT A

Epsilon E-Steer Sensor
History of Furukawa Slip Ring Plating Change

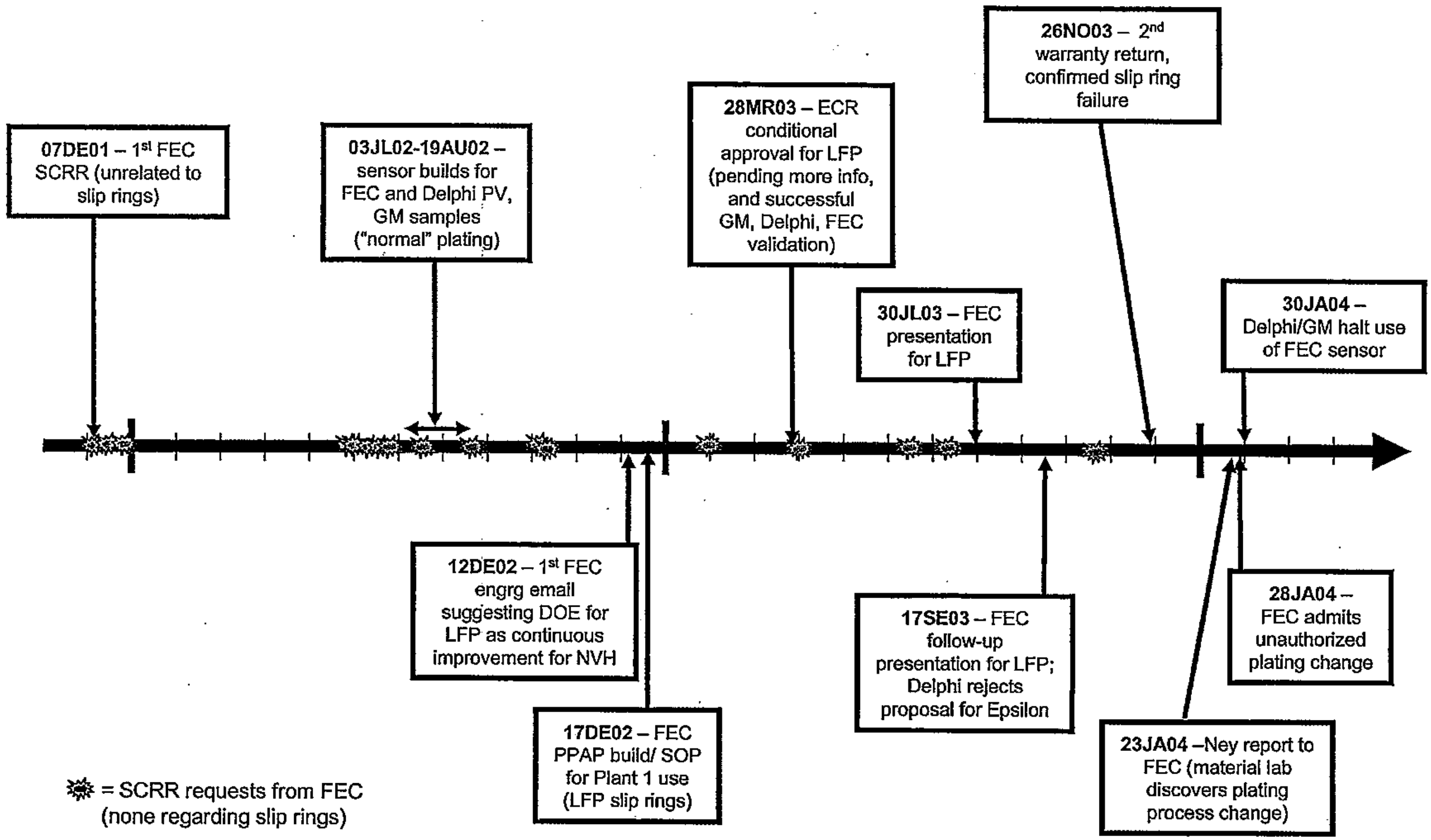


26MR04/dms

EXHIBIT A-1

Epsilon E-Steer Sensor

History of Furukawa Slip Ring Plating Change



26MR04/dms

- Acronyms:
  - Epsilon = GM code name for a certain new vehicle program
  - E-Steer = Delphi trademark name for Electric Power Steering system
  - SCRR = Supplier Change Request/Review
  - FEC = Furukawa Electric Company
  - CDR-1 = Critical Design Review – 1st update (2nd meeting)
  - PV = Product Validation (testing)
  - LFP = Low Friction Plating (i.e. Furukawa term for parts which include PTFE in the plating process)
  - PTFE = polytetrafluoroethylene (i.e. same as trademarked product Teflon)
  - "normal plating" = Furukawa term for plating process with pure gold (i.e. not including PTFE)
  - GM = General Motors
  - DOE = Design of Experiments (i.e. a study to investigate the impacts of varying certain design variables in order to develop or optimize a product or process)
  - PPAP = Production Part Approval Process
  - SOP = Start of Production (i.e. automotive industry term for the advent of regular production of saleable vehicles, and therefore also components for saleable vehicles)
  - NTF = no trouble found
  - Red-X = is a trademarked problem solving methodology from an outside company

5-PHASE
PROBLEM SOLVING REPORT

INITIATOR: T. Yamamoto(FEC) / S. Takei(FENAAPD)		DEPARTMENT(S):	Production Engineering R&D	CHAMPION:	H. Suzuki
INITIATING REPORT:	GM Verbal	P/N OR PROCESS:	26085186	ISSUE DATE:	8-Apr-04
INITIATING REPORT #: 040704 -002					
VEHICLE NUMBER:		CAR BODY:	GMX380	REQUIRED ANSWER DATE:	None
ATTACHMENTS TO FILE:		DEFECT CODE:		QUALITY CONTACT	Mr. Doug Schuller
ASSEMBLY PLANT:	Delphi Saginaw Plt 1	DEFECT NAME:	Unauthorized material usage	SWITCH BUILD DATE:	(Delphi Saginaw)

I. PROBLEM DESCRIPTION (S) OR QUANTIFICATION:

Implementaion of Internal Improvement (Low Friction type Gold Plating) without Customer's authorization.

The purpose of the change:
1. Reduce Audible Noise: DV sensor have had large deviations in audible noise performance.
2. Also we expected to improve the low temp. performance.

This change has been taken place in prototype buld in February, 2002 (from Serial No. 2058).
Since then, all parts (except PV3 product validation) had Low Friction type Plating, including PPAP and Production parts.

II. IMMEDIATE ACTION (S)

N/A

PERSON RESPONSIBLE: N/A PHONE NUMBER: N/A DATE IDENTIFIED: N/A

III. ROOT CAUSE DETERMINATION(S) :

As of December, 2001, our sensor performance, mainly audible noise level, were not good enough to meet the specification because of conventional gold plating low Process capability.
It was very critical situation. Furukawa needed to seek a resolution to keep the business.
There were a few dicussion of the improvement ideas (Brush change, Overcoat, and Plating type change) with the customer. However no SCRR was initiated for the plating type change, because:
a) We considered that It was Furukawa's Internal Improvement because of plating "type " change. We thought it was our responsibility to improve and to absorb any cost delta to meet the customer's requirement, though this Low Friction type was way more expensive than nomal plating.
(b) The plating process was at Furukawa's tier 3 supplier. Since Furukawa did not have expertise/ knowledge of plating, we did not refer to the details including compostion. We did not activate the formal change process due to lack of knowledge.

Based on this background, the change have been implemented to provide more reliable parts to Delphi without SCRR in February, 2002.

(Ref) Advantage of "Low Friction type Plating"
Frictional coefficient between contact brush and normal gold plating on slip-ring had large deviations, resulting large deviations of audible noise.
FEC test result including durability did show the big advantage of "Low Friction type Plating" in this concern.
We believed it would also improve Low Temperature performance.

In December, 2002 when the plating characteristic was discussed between Delphi and Furukawa again, we realized the necessity of the authorization. But it was difficult at that time to bring up the history and fact because it was after the implementation. On the other hand, we had no concern because all test data indicated good (improved) result. The only concern we anticipated was the cost issue remained internally.

minor *See above* PHONE NUMBER: DATE IDENTIFIED: December, 2001

IV. CORRECTIVE ACTION PLAN. (CAP):

Product:
1.The Low Friction type Plating will be no longer used without the customers authorization.
We will change back to nomal plating with Plastic casing design improvement. (more robust structure with Ribs).

System:
1-1. Review and follow the customer procedure (SCRR, PPAP, and so on)
1-2. Also assign Management to take a full responsibility of Engineering change including Customer notification.
2. Update our Procedure of Engineering change at Supplier to cover Tier 3 or below depending on product impact led by FMEA .

PERSON RESPONSIBLE: *See above* PHONE NUMBER: DATE IDENTIFIED: April, 2004

V. VERIFICATION/VALIDATION OF CAP(S):

Product:
1. Special evaluation test for both type of Plating
2. Full PV testing

System
1. Provide list of every design change item to review at each DR with customer to check we are in right process.
2. Conduct audit at Tier 3 or below supplier depending on product impact led by FMEA.

PERSON RESPONSIBLE: *See above* PHONE NUMBER: DATE IDENTIFIED: April, 2004

SUPERINTENDENT'S APPROVAL

Hiro Suzuki (FEC) / Tommy Yamai(FENAAPD) April 8, 2004 NA

PRINT NAME DATE SIGNATURE OTHER POTENTIAL PROCESSES

EXHIBIT B

.Zuraski, Jeff

From:	Halstead, Kirk
Sent:	Thursday, July 17, 2003 10:44 AM
To:	Masahiro Hasegawa (E-mail); Shintaro Takei (E-mail); Torotani (E-mail); Toshiro Yamamoto (E-mail); Yamawaki (E-mail)
Cc:	Alex Iwanaga (E-mail); Hironori Suzuki (E-mail); Noguchi (E-mail); Arita Taro (E-mail); Sean Xuedong (E-mail); Schuller, Doug ; Ross, Kevin ; Zuraski, Jeff
Subject:	Low Friction Plating Meeting: July 30th

Gentlemen -

I have officially scheduled the meeting for FEC to present "Low Friction Plating" on July 30th from 9:00am to 11:00am in Purchasing conference room 2042C. While I have only invited FEC people, please feel free to bring along "an expert" from your supplier that we can all ask questions to (we strongly suggest this).

As you know from our many discussions, any type of silica and electronics makes Delphi very nervous. Therefore, it will up to FEC/Tocos and your supplier to convince Delphi with high confidence that Low Friction Plating will be ok.

As I mentioned in the PDT the other day, I spoke with Mr. Kevin Ross about what type of information he would like to see. Many of his requests are things we have already talked about. Please be very well prepared for this meeting. We will be looking for the following:

1) Information on the patent: Who is the supplier? When was the patent approved? When was the first application of the patent put into production?
2) Low Friction Plating Usage: What type of parts are low friction plating on (any automotive)? How long have they been in production? What type of environment are the parts used in? What type of warranty is associated with the low friction plating? What is the process of applying the low friction plating (a very detailed picture with dimensions)?
3) Validation - Supplier: How did the supplier validate the low friction plating (copy of test plan)? What type of environment was used to validate it (humidity, temperature, vibration, contaminants, voltage, current, etc.)? Have they done a DFMEA, PFMEA, control plan, etc.?
4) Validation - Furukawa: Show a copy of your test plan and results, representative data of pre and post signals from actual test parts (actual captured data), your DFMEA, PFMEA, control plan, etc., any development testing you have done in the past (arcing test), etc. Be prepared to explain why silica will not transfer to other areas (CP) of the sensor with contact wear.
5) Discuss any concerns, unknowns, questions, etc. that FEC and your supplier may still have related to low friction plating.

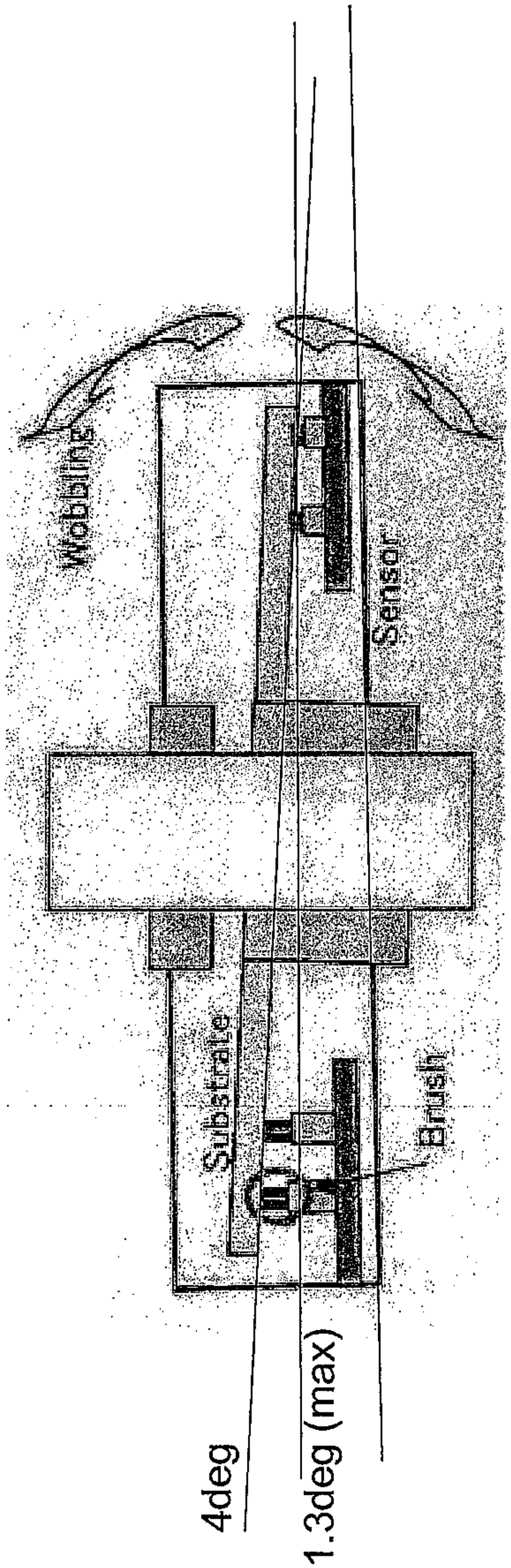
These are the main points we want to be covered. I'm sure as we proceed through the discussion, many other questions will also arise.

Also, would FEC/Tocos and your supplier be open to have Delphi bring in an outside consulting expert to the meeting? Please let us know.

Kirk Halstead
Delphi - Saginaw Steering Systems
3900 East Holland Road
APC-1
Saginaw, MI 48601-9494
P: (989)-757-1233
F: (989)-757-3039
E-mail: kirk.halstead@delphi.com

EXHIBIT C

EXHIBIT D

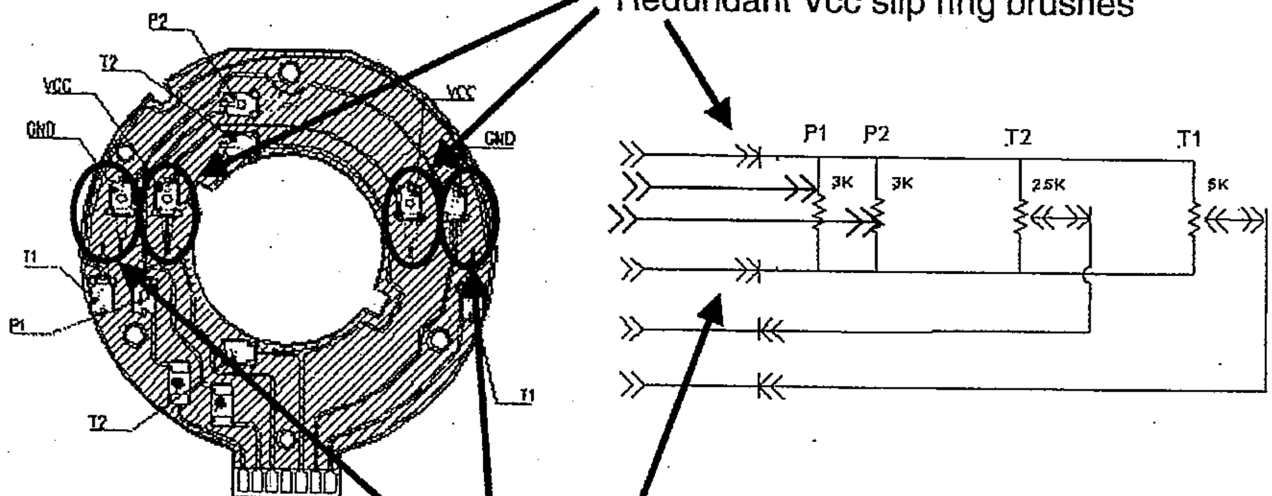


DELPHI

Epsilon E-Steer

Sensor Design Overview

Redundant Vcc slip ring brushes



Redundant Ground slip ring brushes

EXHIBIT E

- Action Title: Slip Ring Plating Analysis Report
- Start Date: 14JA04
- End Date: 11FE04

- Brief Summary:
  - Material analysis of slip rings and contact brushes on samples from warranty, virgin production, and column validation (PV3) wear life testing.
- Objective:
  - Investigate root cause for warranty return sample found to have slip ring failure on bench testing.
    - Note: Failure was initially thought to be located in a specific area, but intermittency of this finding did not eliminate other slip ring failure modes. Initial objective was to determine presence of contaminants such as films, lubricants, particles.
  - After initial results (per findings below), additional samples were provided to lab to investigate any differences in plating materials between warranty sample and the virgin & validation samples.
- Engineering Groups:
  - Deringer-Ney (outside lab, experts/manufacturers of contact materials, including contact brushes used in this design)
- Findings:
  - Warranty and virgin production samples showed significant areas nickel exposure (about 15-30% of surface) and porous, irregular gold plating, due to insufficient gold deposition. PV3 sample had consistent gold plating layer, even after full life wear testing.
  - "High flourine content" was found on the nickel-exposed areas and various sections of the gold-rich regions on the warranty and virgin production samples.
  - Warranty contact brushes exhibited large amounts of "large flakes and compacted debris," consisting variously of gold, flourine, carbon, oxygen (F, C, O are primary constituents of PTFE) and contact brush metals. In contrast, PV3 sample included none of the large flakes, but a "thin layer of adhesively tranferred gold, with areas containing a small level of carbon."
  - Faced with this information, sensor supplier admitted to plating change after validation, which included introduction of PTFE in the Nickel layer (of which a primary constituent is flourine). The addition of PTFE was determined to "increase both the initial porosity and produce an increased tendency of flaking during operation."

EXHIBIT F

- Action Title: Slip Ring Plating Analysis Report (continued)

- Findings (continued):
  - Examination of the suggested slip ring fail location "failed to produce any evidence of a surface contamination unique to this area."
  - No specific contaminant or feature was currently located on the slip ring (after sensor transport and disassembly) which could be directly associated to the fail spot suggested by Delphi engineer. Since typical warranty sensors exhibit slip ring noise intermittently (if noise detected at all), the lack of a specific contaminant in a certain location after disassembly is not unexpected.
  - Further references were provided which demonstrate links between erratic contact resistance performance to defects in gold plating, especially in regard to porosity and nickel exposure (such as "pore corrosion and creep corrosion").

- Conclusions:
  - An unauthorized change to the material/process of slip ring plating (introduction of PTFE) was introduced by the sensor supplier after validation, preventing Delphi and GM from evaluating and validating the appropriateness of such a process change for production usage for this application.
  - The introduction of PTFE into the plating process was determined to create a porous gold-plate layer, leading to poor adhesion, heavy flaking of the gold plate layer, presence of non-conductive material (PTFE) at the contact interface, and concerns about contact resistance performance.
  - The concerns raised in this report merited further investigation of the change to the slip ring plating process as a potential root cause for sensor slip ring field failures.

ISO 9001 REGISTERED

DERINGER•NEY

QS 9000 REGISTERED

Technical Service Report

Subject:

Examination of a Field Returned Steering Sensor

Prepared for:

Bryan Dennis

Delphi
Saginaw Steering Systems
Saginaw, MI

Prepared By:

Dr. E. F. Smith, III
Vice President, Research & Development
Deringer Ney

February 11, 2004

measurements. Based on the electrical data taken by Delphi Saginaw, it was noted that there were no issues with the torque sensor and therefore, it was not examined as part of this report.

Returning to figure 1, it can be seen there are 10 sets of contacts. These are configured into 5 redundant pairs. Each contact is fabricated from 9 wires that are welded to a BeCu spring member. Details of the contact construction and design will be discussed later in this report. Each of these pairs rides against one of the five concentric rings shown in figure 1b. Starting from the outside, the rings are configured as follows: 1) Resistive ink over Au plate, 2) Au plate, 3) Resistive ink, 4) Au plate, and 5) Resistive ink over Au plate. The electrical data supplied by Delphi Saginaw indicated that the noise was found on all the redundant circuits at the same time. This suggested the cause of the noise was likely on one of the common legs and not the individual resistive segments.. Therefore, we were asked to focus on the exposed Au plated rings (rings 2 and 4).

Figure 2 shows low magnification photomicrographs of the Au (track 2) ring from each of the sensors. Both the unused (virgin) sample and the field return from current production show a mottled surface appearance. The wear tracks from the brush contacts are seen on also evident on the PV and field return sample. Figure 3 shows a region from the PV sample where a dark streak was seen on the edge of the wear area. This area was marked for additional SEM analysis. Figure 4 shows three other similar views from the two Au rings on the field return sample. Combined with the region shown in figure 2a, these are the four points on the rings where the contacts were located when the noise event was detected (as marked by Delphi Saginaw). Some of these areas show a slight difference in surface reflection, and all four spots were marked for additional SEM examination.

Figure 5 shows two SEM photomicrographs and the associated surface x-ray spectra from the PV sample. Figure 5a and 5b are from an area similar to that seen in figure 2c, and show a uniform level of Au with some shallow wear tracks from the brush contacts. Small Ni peaks are seen in the x-ray spectrum. Since the plate was reported to be Au over Ni over Cu. The small Ni peaks suggest the 15Kv accelerating potential used for this analysis has penetrated through the Au layer and excited a small amount of x-rays from the subsurface Ni barrier level. The second SEM photomicrograph (5c) and associated x-ray spectrum (5d) are taken from a region similar to figure 3. In addition to the Au and Ni seem in figure 5b, there is also evidence of C, O and a small amount of F. The most likely source for this a residue from a fluorocarbon based lubricant.

Figure 6 contains low magnification SEM photomicrographs from the surface of the Au rings representative of the "noisy area" identifies by Delphi on the field returned unit. As with the low magnification views, the mottled surface appearance is again evident, and there is no evidence of a accumulated debris or tarnish buildup. There was also no feature found that correlated to the variation in surface reflectivity seen in figure 3. As shown in figure 7, similar features were found on the "virgin" sample from current production. Figure 8 contains x-ray spectrum from typical light and dark areas of these surfaces. The lighter areas tend to be Au rich and the dark areas tend to have virtually no Au coverage but show high levels of Ni and P. This is typical of electroless nickel deposits.

A more detailed look at one of the dark areas from the virgin sensor is shown in figure 9. Figure 9a contains a high magnification SEM photomicrograph of one area with a distinctly circular feature in the center of the dark region. This suggests the formation of a surface bubble that

blocked electrolyte contact with the surface and prevented additional deposition. It is possible this occurred between the Ni strike and bulk Ni deposition steps. Second, the Au layer at the sides of the dark (Ni) area shows features suggesting reduced adhesion (small flakes and dendritic appearance along the edge). Additionally, the larger flake in the center of circle appears to have been dislodged from the area highlighted by the arrow. The surface of the flake is not severely distorted, again suggesting it was dislodged without the use of excess external force (i.e.- low adhesive strength). Figure 9b shows the elemental chemistry found near the center of the circular region. The Ni and P peaks are typical of an electroless Ni plate. However, there is a slight distortion along the left hand side of the lower energy Ni peak. This is the region for F, but the peak is not distinct enough to allow a positive identification.

A more detailed analysis of other exposed Ni regions found that many of these did a high F content, and that F rich regions could also be found in various sections of the Au rich regions as well. Representative x-ray spectrum for the showing the F peaks are shown in figure 10. Based on these results, the supplier indicated that a change had been made in the plating process from the original PV sample. The PV sample used a pure Au layer; while current production is using a "low friction" Au plating that incorporated PTFE (polytetrafluoroethylene or Teflon) into the plate. It is likely that many of the submicron grey features on the right side of figure 9a are some of the PTFE nodules. The "low friction" process was adapted to overcome some objectionable acoustic noise found under low temperature sliding conditions.

In addition to the surface examinations, cross sectional views were prepared from the field returned and retained PV sample. In order to prevent edge rounding during polishing, the sections were first coated with electroless Ni overcoat. As seen in figure 11a, the original PV sample had a uniform Au level with no evidence of surface breaks. In contrast, the cross section of the field return sample (11b) shows a somewhat irregular Au thickness levels with areas of no Au coverage. This exposed Ni area is consistent with the previous surface SEM photomicrographs.

As noted earlier, the sliding contacts that mated against the PC board utilized a wire microbrush construction. As shown in figure 12, nine 0.87 mm diameter Paliney® 7 wires were welded on to a 0.06 mm thick BeCu cantilever spring. The use of a design with redundant, parallel points of contact is often used to provide low noise signals in applications that might be subject to high levels of tarnish films or resistive debris in the wear track. Although a more detailed discussion of the attributes of this design will be discussed later, the major benefit of a parallel contact construction is that it offers multiple conduction paths. Therefore, in order for a surface contaminant to cause a significant noise event must disrupt all nine paths simultaneously.

With this in mind, the sliding contacts of the field return sensor were examined in the SEM. Figure 13 shows the debris build up around two set of contacts. The point of physical and electrical contact to the ring appears to be a somewhat "cleaner line" running down the center of the debris pattern. The debris appears to be a combination of large flakes and compacted debris. Additionally, a large number of smaller flakes can be seen attached to the wires outside the contact region. These flakes were found to be similar to the flakes found on the PC board. Figure 14 shows various x-ray spectra from this debris. The debris is found to vary from: 1) nearly pure Au (14a) to 2) a mixture of Au plus F (14b note the absence of the C peak expected for PTFE) to 3) a more complex mixture (14c) showing evidence of the wire (Pd, Ag, Cu) plus the Au plate plus other elements form either the PTFE in the plate or an external lubricant (C, O and F).

A similar SEM analysis of the PV contacts is shown in figure 15. Figures 15a and 15b show the debris build up on the contact tips. In contrast with the field return sample, the wires show distinct flats at the point of contact. Additionally, there are none of large flakes similar to those seen in figure14. The x-ray data shown in figures 15c and 15d suggests the flats are primarily a thin layer of adhesively transferred Au, with the darker areas containing a small level of C.

Discussion:

The original objective of this work was to examine the field returned sensor and help identify a potential root cause or causes for the Delphi documented noise spikes. It was reported that the noise spikes were found on all the sensor outputs and only occurred when the sensor rotor passed over a specific geometric position. Based on this data, it was assumed that root cause would be tied to some contaminant on one of the two power (Au covered) rings within the sensor. Since these rings provide the power used in the potentiometric position measurements, any disruption of this signal would result in a simultaneous noise spike on all the measurements. A thorough examination of the area (marked by Delphi), using both optical and SEM techniques, failed to produce any evidence of a surface contamination unique to this area. The investigation did produce two areas of concern- 1) the Au plate did not completely cover the subsurface Ni plate and, 2) the sliding motion of the contacts on the Au plate produced a large volume of flakes and wear debris that were found on both the wear track and the mating contacts. Subsequent analysis indicated that these features were common to current production, but were not found on the original PV samples.

Although no evidence was found to directly associate these features with the current field problem, they are highlighted because they offer the potential for creating future noise problems. The reason for using a gold plated surface in an electrical contact application is that Au does not tarnish or oxidize. Therefore, Au plated surfaces will provide low and stable contact resistance over a wide range of applications and environments. However, it has also been documented that defects in the Au plate can lead to erratic contact resistance performance. Perhaps the most studied defect is porosity exposes the Ni underplate to the service environment. Past studies (references 1-4 in the appendix) have shown that both pore corrosion and creep corrosion are possible, depending on the environment. Pore corrosion can be thought of as a small defect that exposes the Ni underplate, and the resultant chloride and sulfate corrosion products mirror the size of the pore. In creep corrosion, the corrosion products actually begin to "creep" over the surface of the Au plate and actually increase the size of the high resistance spot (well beyond the size of the initial pore). Since both products only require exposure of the Ni underplate and ppm level concentrations of Cl and S vapors, it is likely that these phenomena would be active in the sensor. Based on the SEM photomicrographs shown in figures 6 and 7, somewhere between 15-30% of the overall surface is exposed Ni, and susceptible to this type of signal degradation. It should be noted that these phenomena are generally studied under static or stationary contacts- and it is not known how the kinetics are influenced by the continuous wiping anticipated for the sensor. In contrast, figure 5 shows the PV sample to have a continuous, pore free Au electroplated layer.

It should also be noted that the x-ray analysis indicates that for current production the Au plate contains a measurable level of F. In subsequent discussions with Delphi and their supplier it was learned that the plate contained co-deposited nodules of PTFE (polytetrafluoroethylene or Teflon). As noted above, the PTFE was added to reduce audible noise at low temperature. Clearly in comparing figures 5 and 6, the addition it also increased both the initial porosity (or exposed Ni) and produced an increased tendency of flaking during operation. One possible explanation for the increased flaking is the fact that PTFE is not easily wet by other materials. This is one of the reasons why is acts an effect lubricant. The fact that it is not easily wet suggests that the interfacial strength between the PTFE and the Au plate will be quite low. Therefore, wherever the PTFE is incorporated (either at the Au-Ni interface or within the Au plate), it acts to reduce the level of strong metal to metal bond area and replaces it with a much weaker metal to PTFE interface. The net reduction in cohesive strength should make it much easier to for the frictional forces between the contact and Au plate to tear sections of the plate away during sliding. Although overtime, the PTFE should spread over the surface and decrease the frictional forces, the SEM photomicrographs in figure 13 suggest that this plating process results in increased flaking and debris build up on the contact.

Figures 14a-c indicates that the compacted debris found on the leading and trailing edges of the contacts as having somewhat variable chemistry, from the highly conductive (14a) to the highly resistive (14c). Although it is possible that a noise spike could occur if this compacted layer did break free and rotate under the contacts, this would be a random event and not likely tied to a specific geometric location on the ring. Therefore, although the presence of this debris field raises some concern for long term reliability, it does not appear to be the root cause for the noise spikes found on the field returned unit.

Returning to figure 12, the contact design utilizes nine Paliney® 7 wires configured to provide independent, parallel electrical paths for the signal. As shown in figure 16, the benefit of using the parallel wires comes from the fact that any contaminant that forms at the interface of each wire can be treated as a parallel rather than series resistance. For example, as illustrated in the lower half of figure 16, if a surface film of 100 milliohms was found on the tip of each wire, and n parallel wires were used to make the contact, the resulting net contact resistance is actually 100/n milliohms. If the resistance is different at each contact (a more likely real occurrence) the resistance is calculated via the equation for parallel resistance using a different value for each finger.

However, the most important design consideration is that the wires all have mechanical independence as well as the parallel electrical path. The importance of this is illustrated in figure 17. The drawing suggests what could happen if the contact rides over an area where there is a uniform tarnish film equivalent to 100 milliohms and a highly resistive particle with a 2 ohm (or 2000 milliohm) resistance. For the single point of contact (scenario 1), both the particle and the film act as a series resistor. The overall resistance is then the sum of the two values or 2100 milliohms. If the contact is designed properly, and the individual wires have enough mechanical independence such that the particle only lifts up one wire, the net resistance is very similar to n-1 parallel contacts. For the example shown (scenario 3), there are four parallel contacts, and as noted in the example found in the previous figure , this would have a net resistance of 25 milliohms in the absence of the particle. However, the particle effectively negates most of the current flow from the lifted leg, this acts very similar to a three parallel contact construction (i.e.- 32.8 vs. 33 milliohms). A similar analysis with nine wires indicates that if only one of the nine

wires was lifted by the 2 ohm particle, the overall net resistance would rise by only 1.3 milliohms. (from 11.1 mohm if all were directly touching the 100 mohm film to 12.4 mohm for the single lifted contact). Even if four of the nine were lifted by the particle, the overall resistance would still be only 19.2 mohms.

However, a far more damaging scenario is illustrated by scenario 2 in figure17. In this case, the wires do not have mechanical independence, and as a single wire rides over the particle, the rest of the wires are lifted off the film. This results in a single point of contact. This can occur when the relative stiffness of the individual wires is too high in comparison to the supporting spring. It may be helpful to think of this construction as a supporting arm (BeCu spring) with fingers (Paliney wires) at the end of the arm. The design issue is to make sure the "fingers" are flexible enough to allow independent movement over any potential obstacle. If the fingers are too stiff, as one or more of the fingers try to deflect up and ride over the obstacle, they actually lift the other fingers off of the opposing substrate and the electrical path moves from a parallel to a series path. In terms of the schematics seen in figure 17, we move from scenario 3 to scenario 2, and the potential for large noise spikes increases dramatically. Because differences in thickness, width and cross section all effect the section modulus of a cantilever spring, accurately modeling the exact geometry shown in figure 12 is difficult and outside the scope of this report. However, it is possible to provide some directional guidance on the design issues for this style contact.

As noted earlier, the use of a multi-point design concept is recommended for applications requiring very low noise levels. Figure 18, (a plot of the net resistance versus the number of fingers) shows the knee of the curve to be in the range of 3-7 contacts. Although this curve is based on a uniform tarnish film of 2 ohms under each finger, the relative shape will not change with resistance. From this curve, it is also evident that adding more than nine fingers will not significantly improve the overall noise response. The only advantage of more fingers is that it increases the overall coverage area of the contact, thereby reducing the chances of a single particle or debris field covering all the contact points. This slight improvement is generally outweighed by the increased difficulty associated with manufacturing and handling a contact with ten or more fingers.

In order to maximize the advantages of parallel conduction paths, it is necessary to ensure that the relative spring rates for the fingers and associated support arm are set correctly. First, the spring rates on the fingers should be set so that each finger has enough flexibility to "climb" over the height of the anticipated particulate/film layers. This must be done without either1) plastically deforming the finger, or 2) generating enough spring force to lift the supporting arm to the point where the remaining fingers lose contact with the mating surface (i.e.-scenario 2 in figure 17). Also, the total gram force on the fingers (sum of the force resulting from both the finger deflection and the arm deflection) balanced so it acts to mechanically dislodge/disrupt most particles and films, but does not cause excessive wear of the mating surface. Based on our experience with Paliney contacts in other automotive applications, we generally recommend something in the range of 2.5-5 g per point of contact. However, we do not have any experience with the PTFE co-deposited Au. Most of our experience is based on mating to polymeric based resistive inks. For nine wires, our generalized recommendations would place the total gram force in the range of 22.5 to 45 grams.

We do not advocate that designers use this entire range for their tolerance level. We have found a range of ±25% of the nominal is usually adequate to allow for fabrication and stack up

tolerance considerations. The nominal level is generally set somewhere within the range noted, with an attempt made to balance low noise (favored by higher gram forces) and the low wear (favored by lower gram forces). Both factors are normally empirically tested at the extreme of the environmental factors anticipated in field use. For example, high temperatures tend to increase tarnish/oxidation film thickness levels and lead to the use of higher gram forces. Extreme vibration can lead to contact lift off (favoring higher gram force to maintain contact), but it can also increase dither wear (a major problem thin or fragile coatings on the mating surface). Tests are using done to include full sweep cyclic measurements to access the effect of wear and accumulated debris.

Since the field return sensor demonstrated excessive noise, I would recommend investigating an increase in the overall gram force. I am assuming that the noise spike was created by either lift off or by some foreign debris that was dislodged in transit (so it was not present/visible during our investigation). I would also look to re-balance the force by reducing the spring rate on the fingers- to allow for a higher level of mechanical independence of the individual fingers and increase the spring rate of the arm. There are a number of geometric changes that will accomplish this objective. I would first look to slightly increase the length of the fingers and slightly increase the thickness of the BeCu arm. The exact dimensional shifts will require a stress analysis to ensure that the new design doesn't exceed the yield stress of either material. This is especially true if the new design changes the initial free height or overall deflection to reach the higher gram force levels.

An example of this is shown in figure 19, which plots the gram force vs. deflection for some simplified versions of the arm and a single wire finger. The original dimensions for the existing arm design were estimated by an isolated rectangle of BeCu .06mm thick, 4.06 mm long, and 2mm wide (modulus = 13,500 Kg/mm^2 as per Brush Wellman data sheets) The finger is estimated as an isolated Paliney 7 wire .087mm dia. by 2 mm long. (modulus 12,000 Kg/mm^2 as per material property sheets- Deringer- Ney). As you can see, this over simplified approach shows the arm to have a slightly higher spring rate than the finger. This means that if they were isolated contacts, the finger will first move a small amount until the force generated by the finger is high enough to move the arm. After that point, any additional deflection will be shared by both components. In actual fact, they are mechanically joined by a very stiff welded region composed of the BeCu arm, the wires and the shorting strip.

Based on the variation from the actual design, these plots are only meant to provide directional guidance. In that regard, I have also included data for a slightly longer finger (2.3 mm vs. 2 mm, at the same diameter) and a slightly thicker arm shortened to accommodate the extra finger length (.07mm thick and3.76mm long vs. .06mmthick by 4.06mm long for the original). Both changes act to increase the difference between the finger and arm, providing more independent motion for the finger and less likely that the motion of one finger will lift the entire contact. Again, I have not calculated the resultant stress levels or total gram force for the new dimensions- they are meant only to provide directional guidance and not as specific dimensional recommendations. As noted early, any changes on the contact dimensions should be tested to evaluate the balance between noise and wear. It should also be noted that if the current supplier is not capable of maintaining the consistency of the Au plate found on the PV samples, a protective covering over the Au should be considered. This would also require proper validation testing.

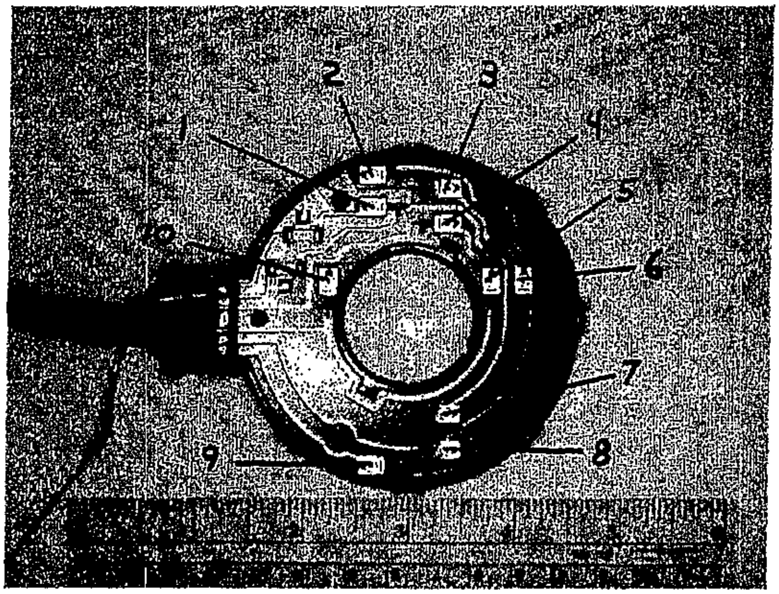


Figure 1a) A low magnification view of the contact layout for the position measurement side of the steering sensor

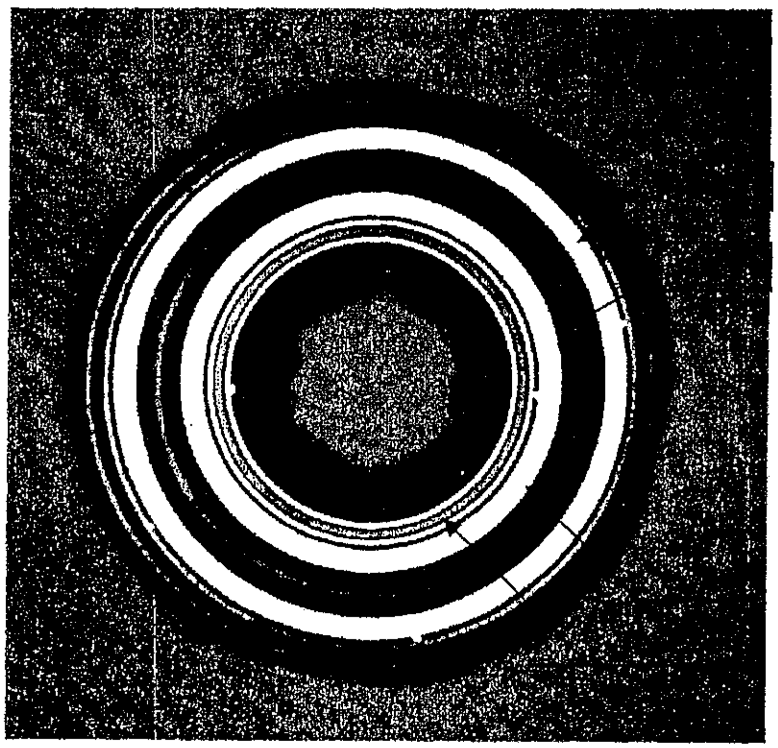


Figure 1b – A similar low magnification view of the PC board layout that mated to the contacts shown in figure 1a. In the original Delphi print-
Ring 1 = T1 slip ring
Ring 2 = GND slip ring
Ring 3 = P1-P2 resistor ring
Ring 4 = VCC
Ring 5 = T2 slip ring

Figure 1- Low magnification photomicrographs of the field returned unit after dis-assembly to show the contacts and PC board for the position monitoring portion of the steering sensor.

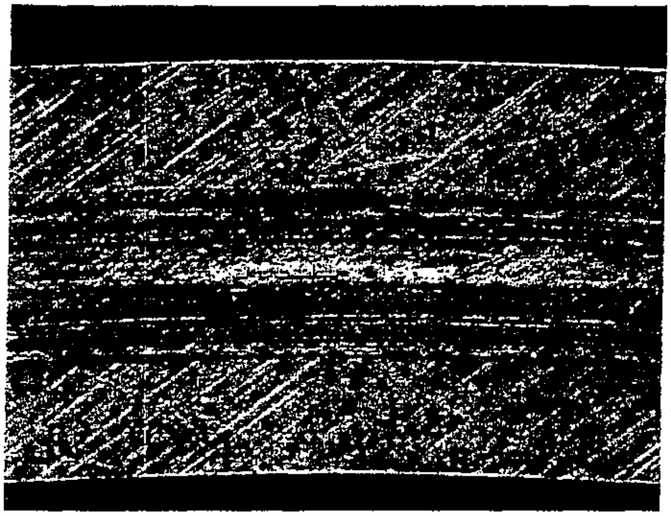


Figure 2a –
Field return sample
Track 2. position on
track mated to contact 8
at "noisy" rotor location

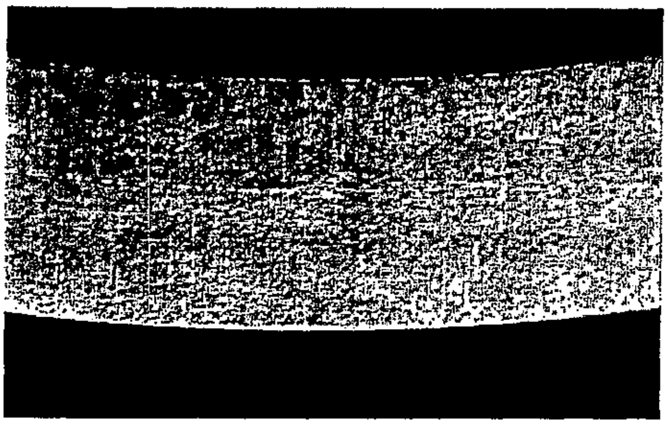


Figure 2b
Current production
unused, virgin sensor
Track 2 apparent
dither location

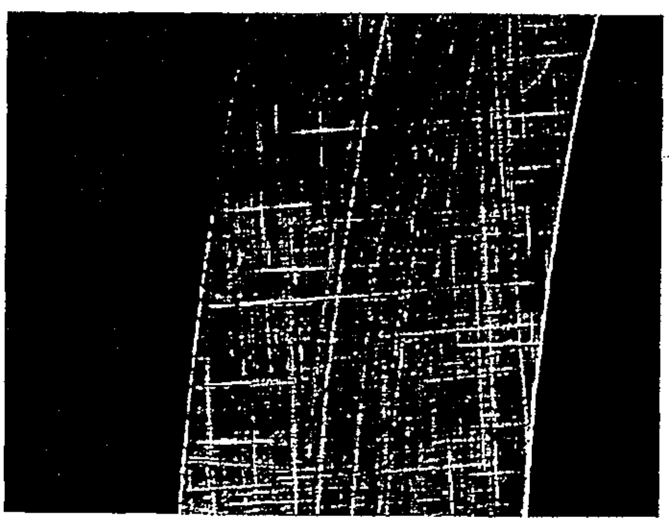


Figure 2c)
PV sensor
Track 2,
random location

Figure 2- Low magnification photomicrographs showing the surface finish on the Au plated rings for the three sensors supplied by Delphi-Saginaw.

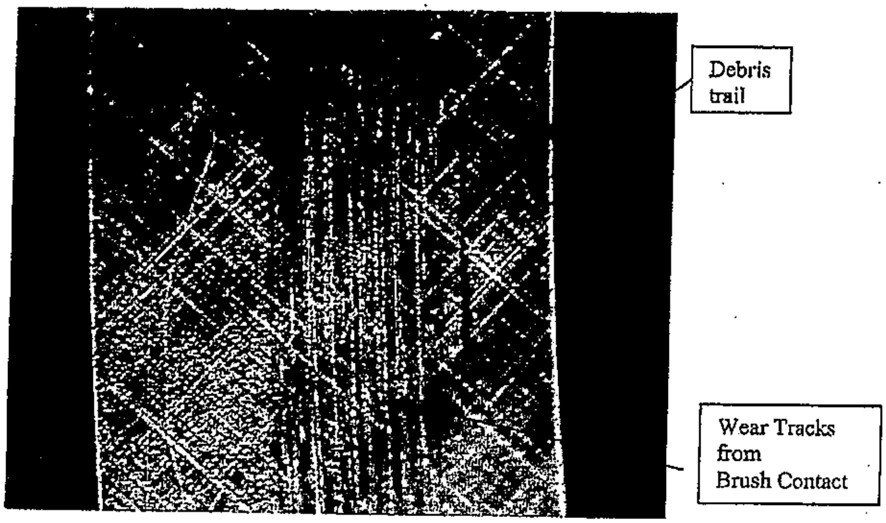


Figure 3- A low magnification photomicrograph taken at another location on track 2 of the PV sensor illustrating some built up wear debris adjacent to the wear track created by the nine wire contact.

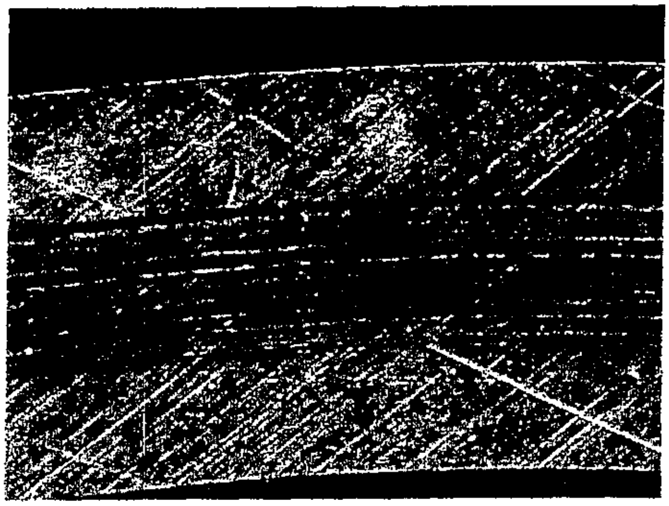


Figure 4 a
Track 4
marked location
for contact 7
at noise event

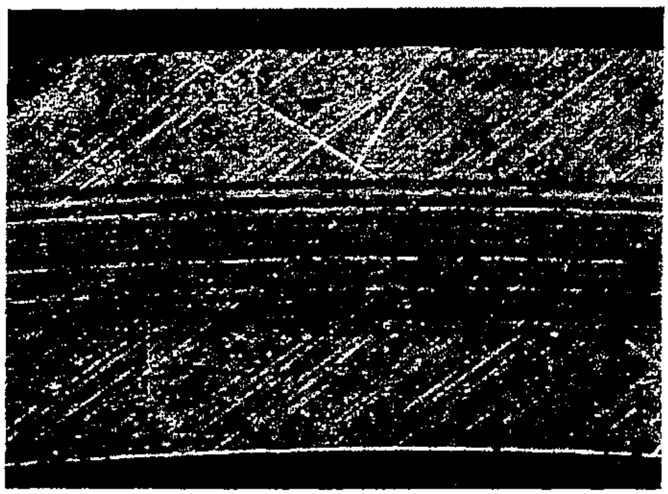


Figure 4 b
Track 2
marked location
for contact 3
at noise event

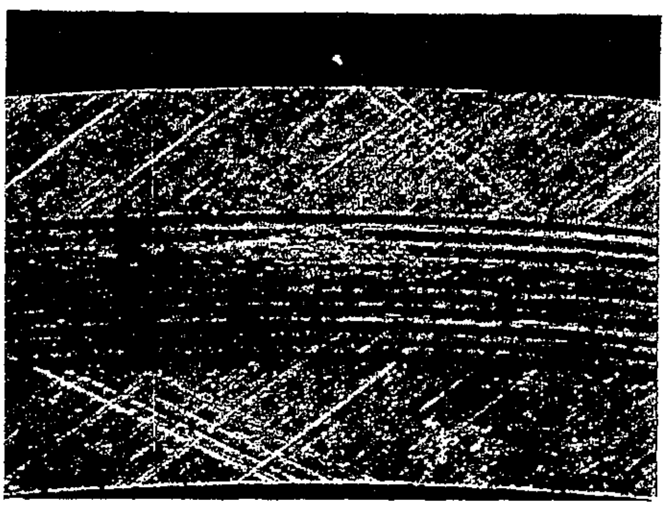


Figure 4 c
Track 4
marked location
for contact 4
at noise event

Figure 4 – Low magnification photomicrographs showing the Delphi marked regions on the Au rings where the contacts resided at the noise event

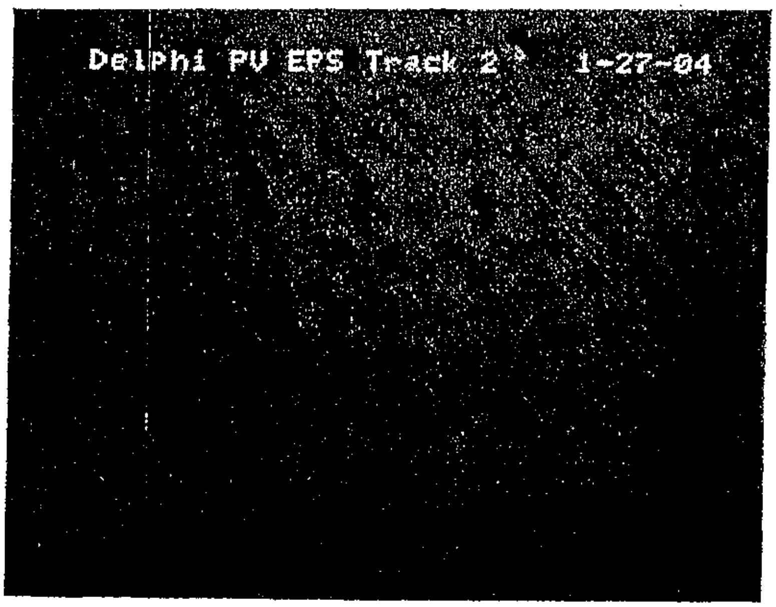


Figure 5a - SEM photomicrograph of the Au plated region on track 2 from the PV sensor

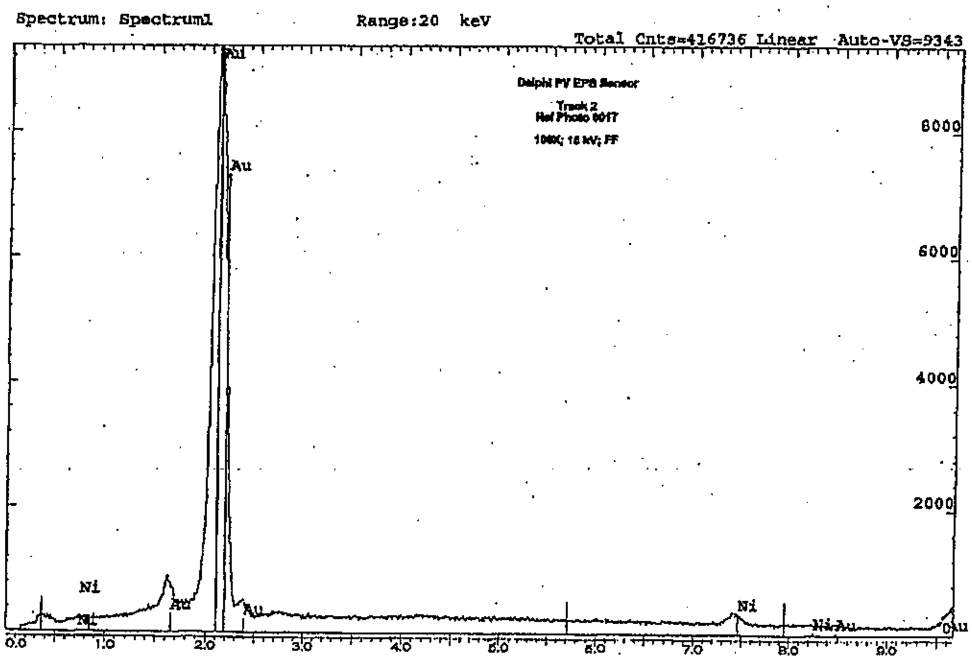


Figure 5 b- X-ray spectrum from the surface of track 2 on the PV sensor.

Figure 5 - SEM photomicrographs and the associated X-ray spectra from two locations on track 2 of the PV sensor.

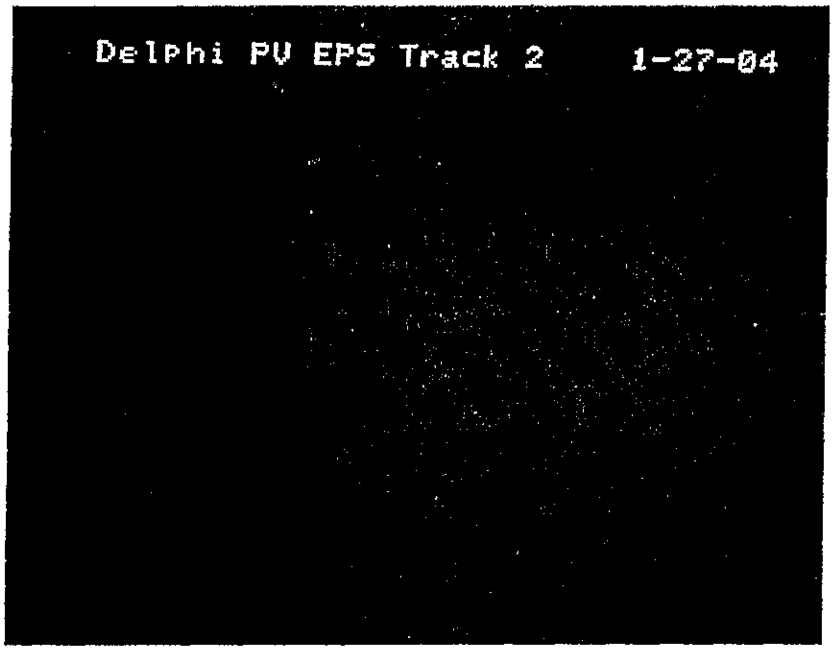


Figure 5c-
SEM photomicrograph of the dark streak shown in figure 3

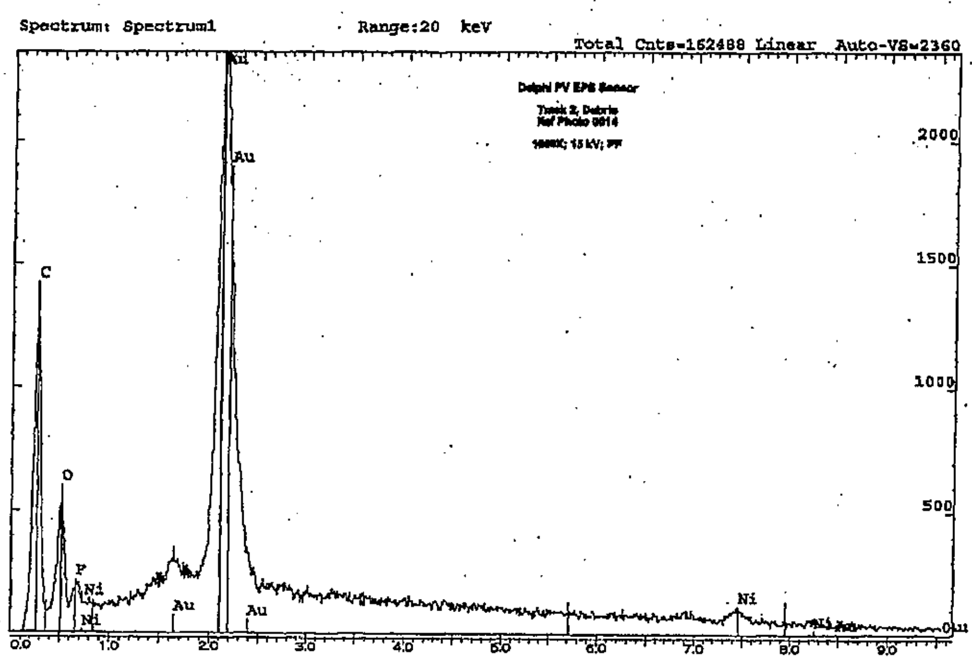


Figure 5d
X-ray spectrum from the dark streak shown in figures 3 and 5c.

Figure 5 - SEM photomicrographs and the associated X-ray spectra from two locations on track 2 of the PV sensor.

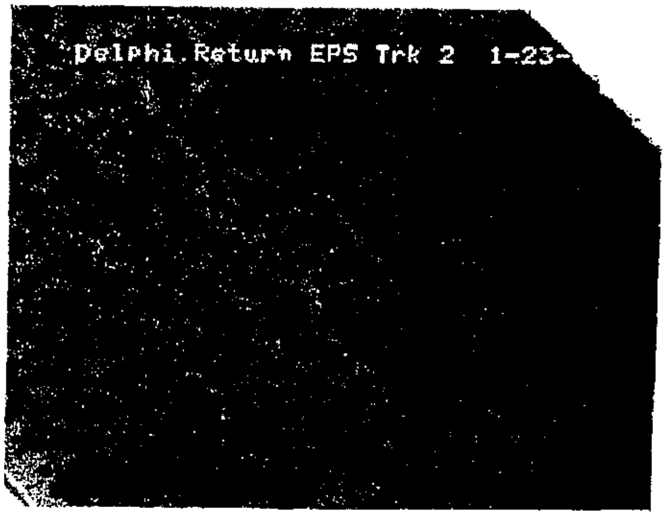


Figure 6a – SEM photomicrograph from one of the noisy contact locations on track 2 of the field returned sensor.

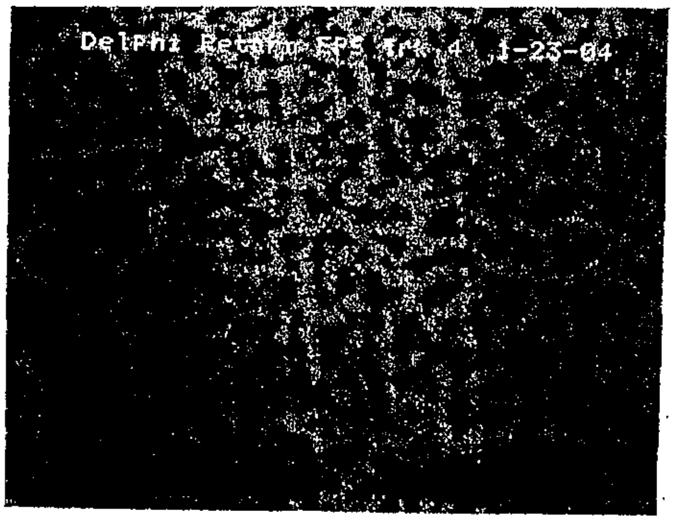


Figure 6b – SEM photomicrograph from one of the noisy contact locations on track 4 of the field returned sensor.

Figure 6 – SEM photomicrographs from the noisy contact locations on tracks 2 and 4 of the field returned sensor.

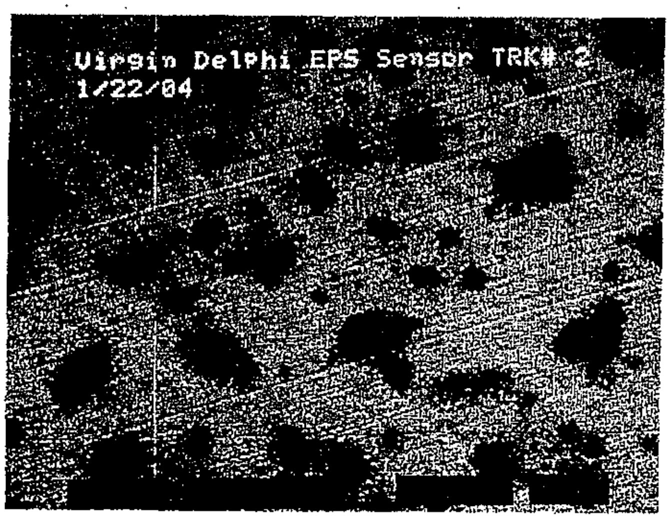


Figure 7 – A higher magnification SEM photomicrograph of the surface of a Au plated ring from the current production, virgin sensor.

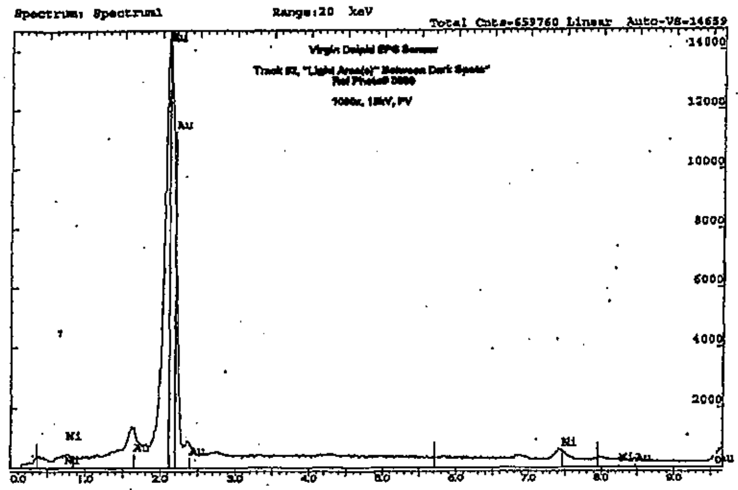


Figure 8a –X-ray spectrum typical of one of the lighter areas in figure 7.

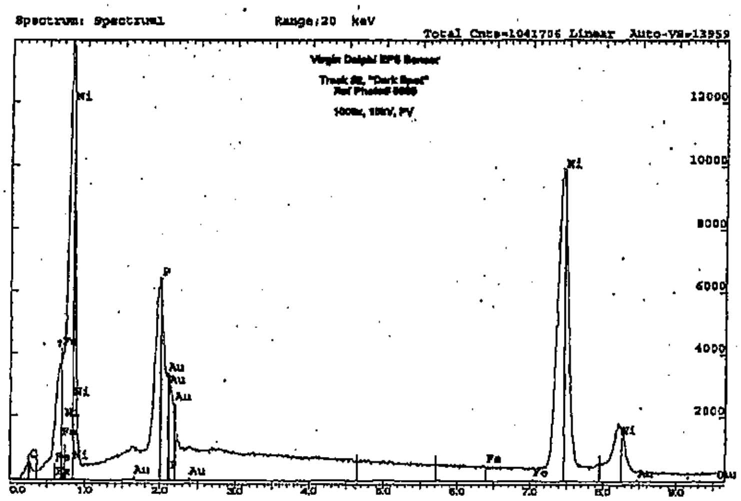


Figure 8 –X-ray spectrum typical of one of the darker areas in figure 7.

Figure 8 X-ray spectrum from the light and dark areas of figure 7. Similar elemental surface chemistry results were found on the Au plated rings in the field return sensor.

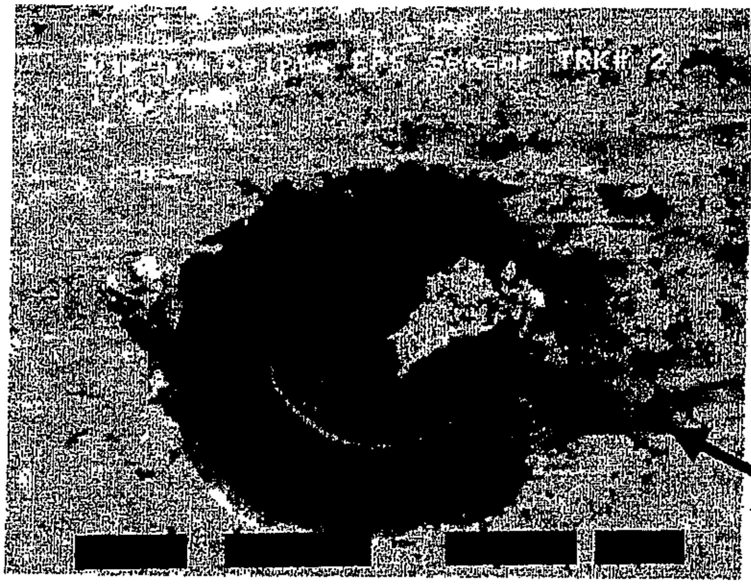


Figure 9a

Likely original site for large flake before it "rotated" loose

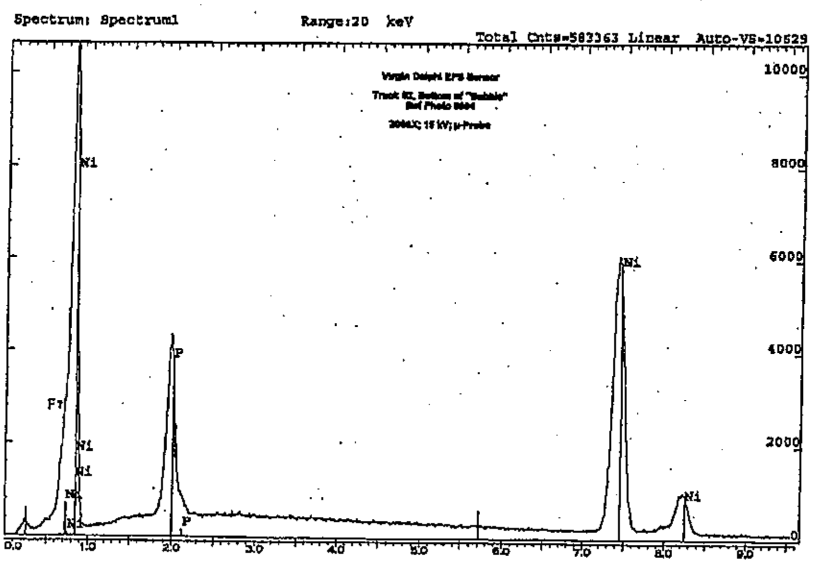


Figure 9b X-ray spectrum from the center of the circular spot shown in 9a.

Figure 9 SEM photomicrograph and X-ray spectrum form a circular dark regions on the surface of track 2 from the "virgin", current production sensor.

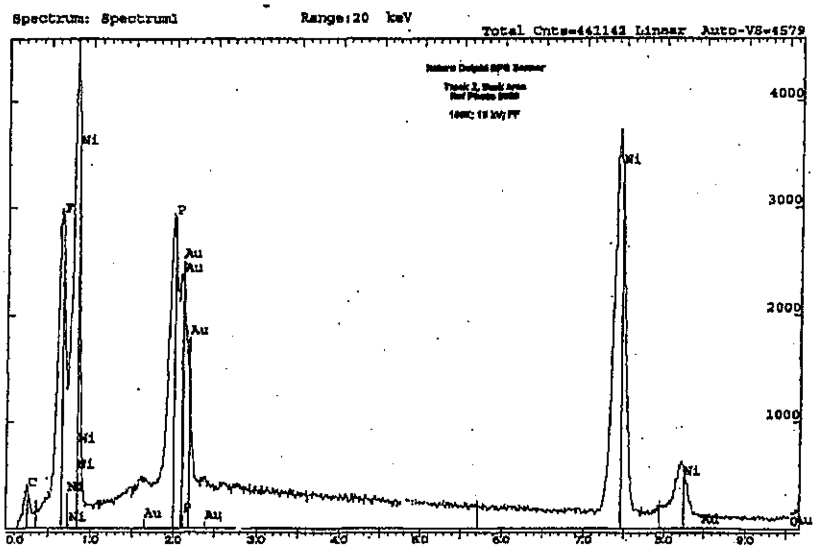


Figure 10 X-ray spectrum showing the presence of a high F peak along the edge of a dark area in the field returned unit.

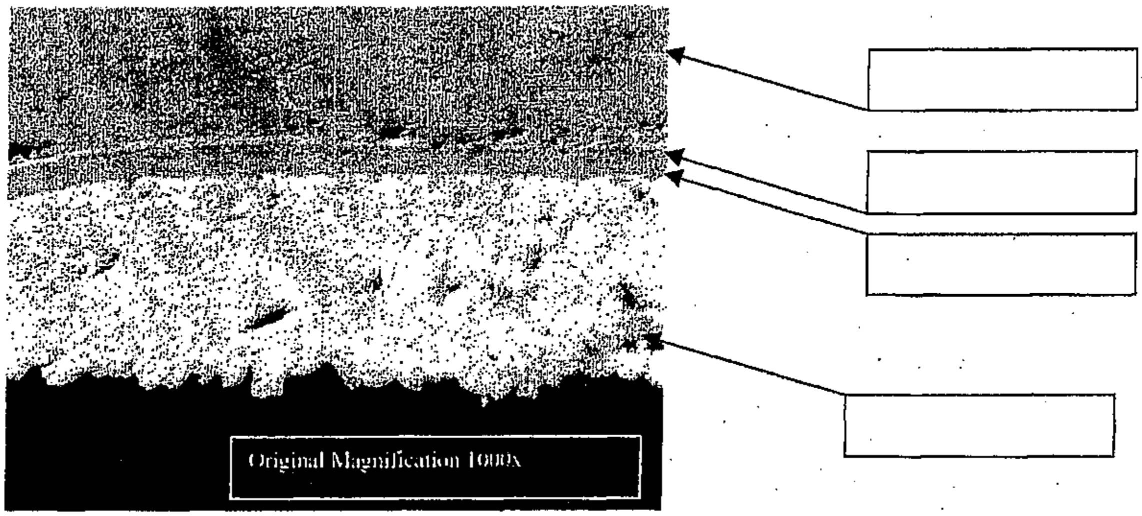


Figure 11a- Cross sectional view of the plated structure found on the field returned sample. Note irregular thickness and "zero coverage" areas in the Au layer.

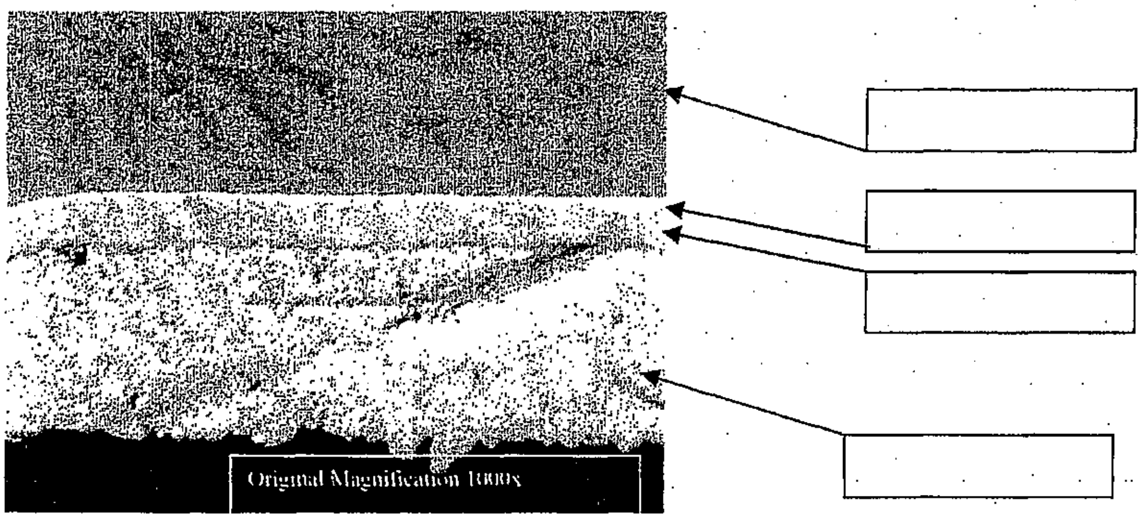


Figure 11b- Cross sectional view of the plated structure found on the PV sample. Note uniform thickness and complete coverage for the Au layer

Figure 11 Cross sectional views of the plated structure found on both the field return and retained PV samples.

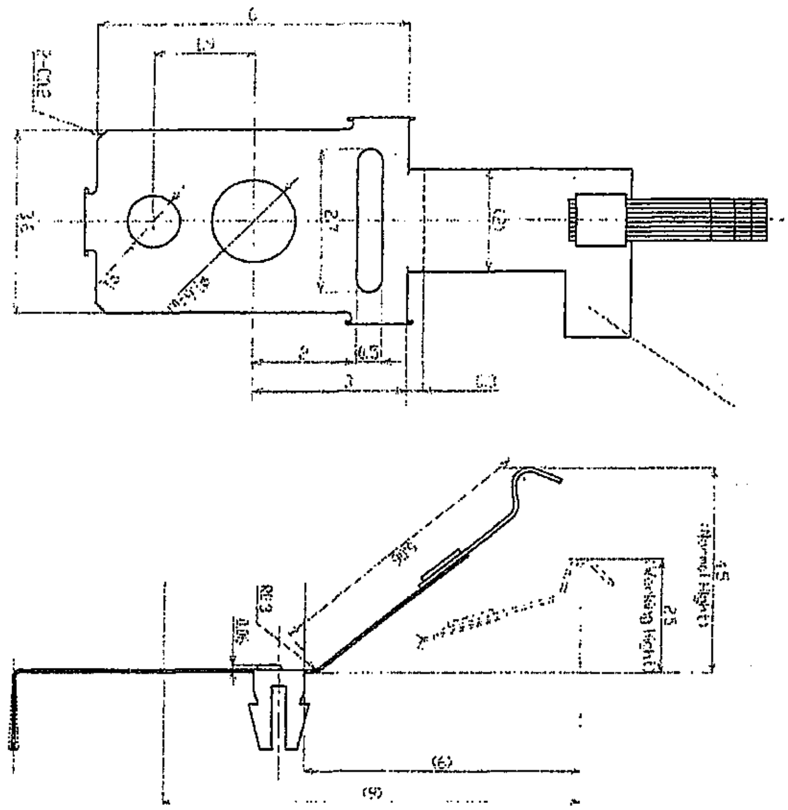


Figure 12 Drawing illustrating the multiwire construction used for the sliding contacts.

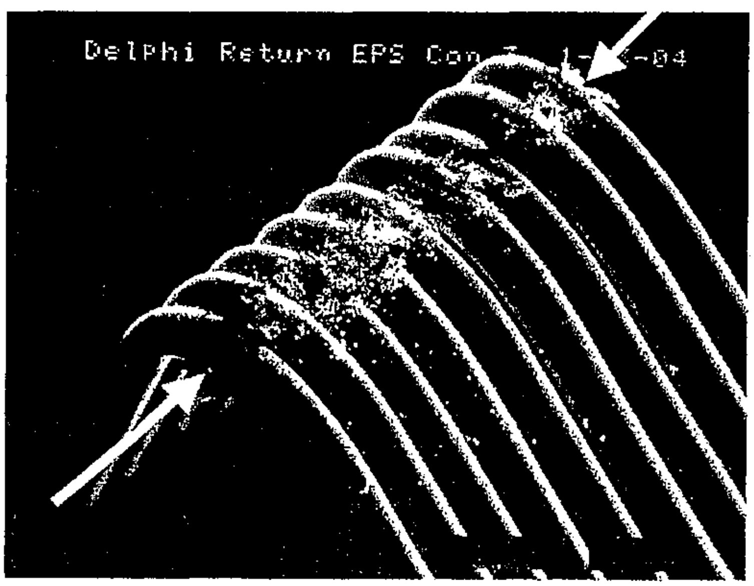


Figure 13a – SEM photomicrograph of contact 3 taken from the field returned unit. The white arrows show the contact area that mated to the Au plated ring.

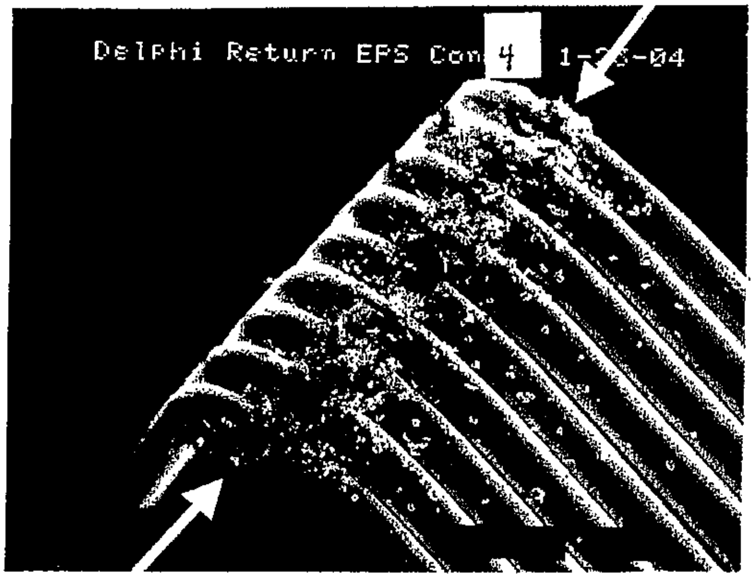


Figure 13b – SEM photomicrograph of contact 4 taken from the field returned unit. The white arrows show the contact area that mated to the Au plated ring

Figure 13- SEM photomicrographs of two wire microbrush contacts from the field returned sensor. Note the high volume of flakes and compacted debris on both the leading and trailing edges of every contact.

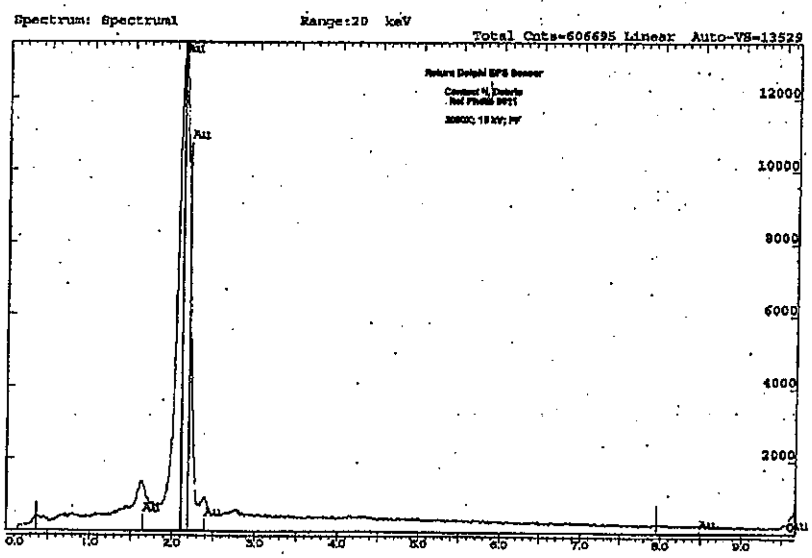


Figure 14a X-ray spectrum from one of the larger flakes contained in the wear debris shown in figure 13b

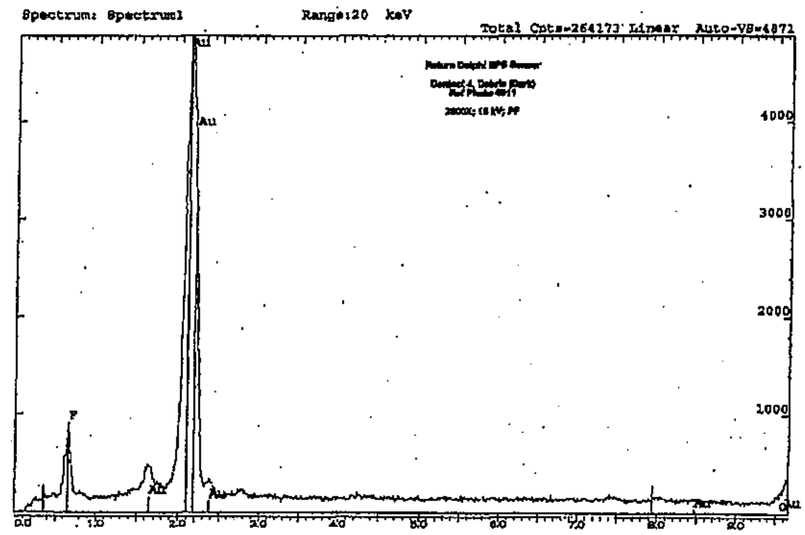


Figure 14b X-ray spectrum from the wear debris shown in figure 13b

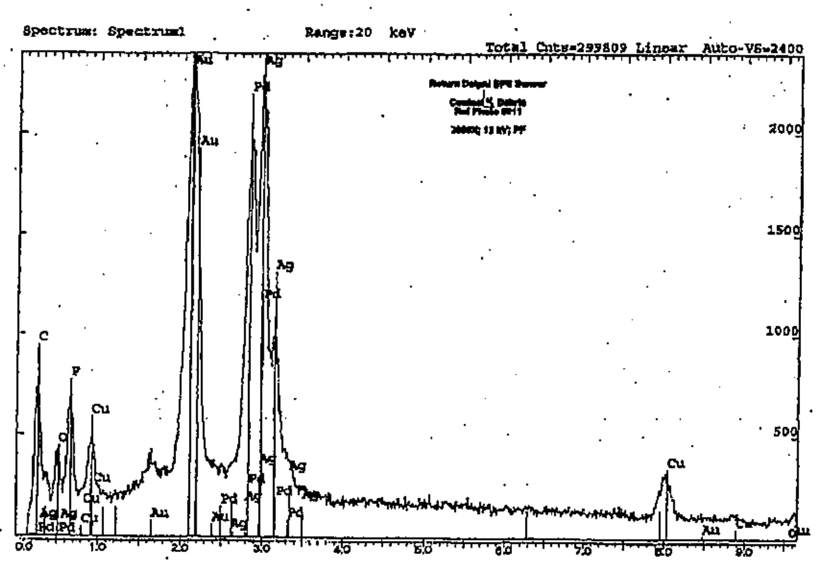


Figure 14c X-ray spectrum from the wear debris shown in figure 13b

Figure 14 –X-ray spectra from the flakes and compacted debris found on the wire contacts from the field returned sensor.

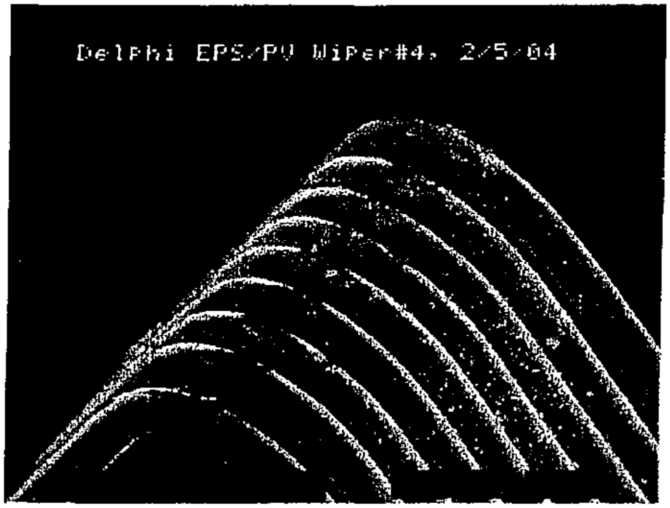


Figure 15a – SEM photomicrograph of contact 4 taken from the PV sensor.

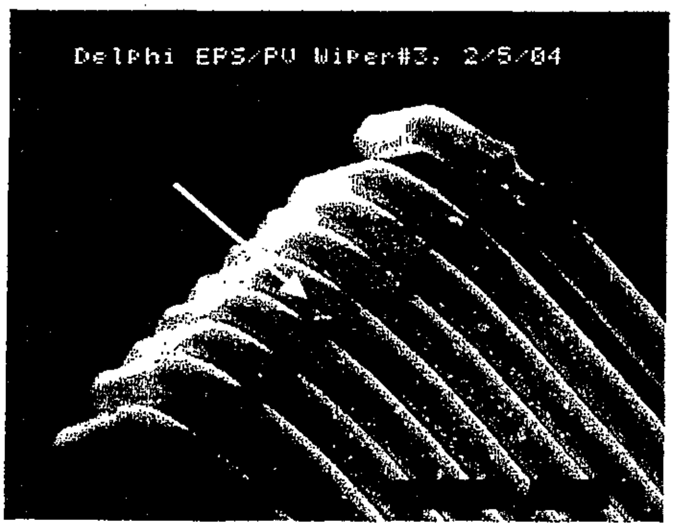


Figure 15b – SEM photomicrograph of contact 3 taken from the PV sensor. White arrow denotes flake analyzed in figure 15d.

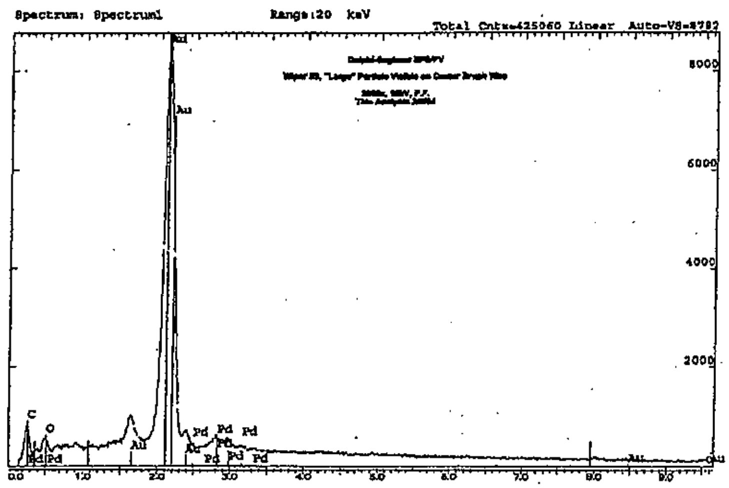


Figure 15c – X-ray spectrum form the wear flat found on contact 3 shown in figure 15b.

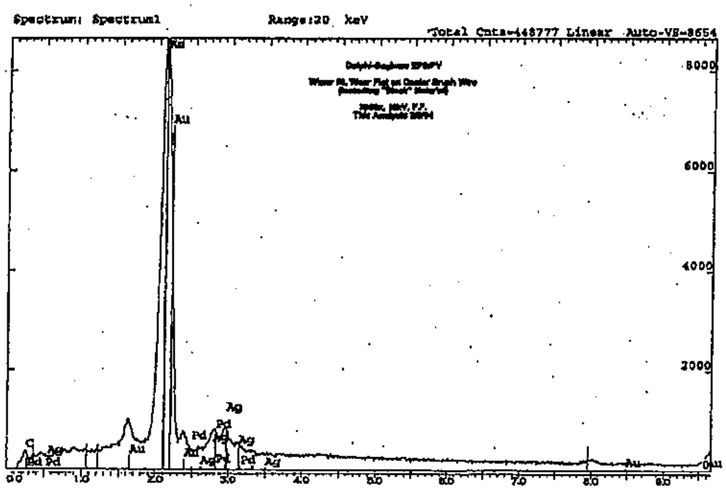


Figure 15d – X-ray spectrum form the flake found on contact 3 highlighted by the arrow in figure 15b.

Figure 16
Fundamental Resistance calculations

Formulas used to calculate the net resultant resistance for Parallel and Series networks

Series-single contact point

$$R_{TOTAL} = R_1 + R_2 + R_3 + \ldots R_T$$

Parallel-multiple fingers /multiwire

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_T}$$

Example using the multiple finger formula to calculate the resulting net resistance for the case where a uniform film of 100 milliohms is under each of the contact points

Equal film under each finger (film =100 milliohms)

total # of fingers	*Resultant Net Resistance*
1	*100 mohms*
2	*50 mohms*
3	*33.3 mohms*
4	*25 mohms*
9	*11.1 mohms*

Figure 17
Illustrations of how contact fingers can interact with particles and surface films

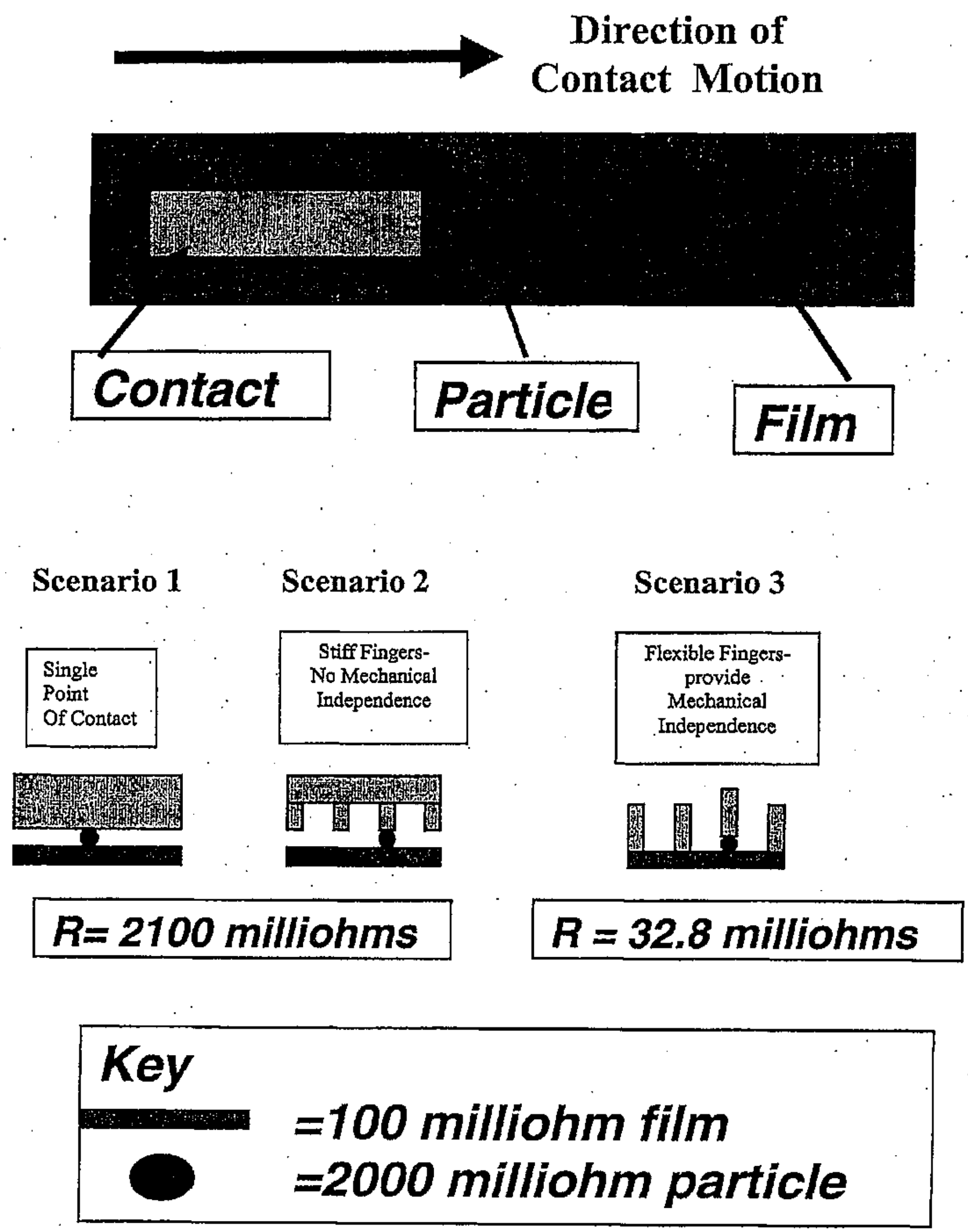
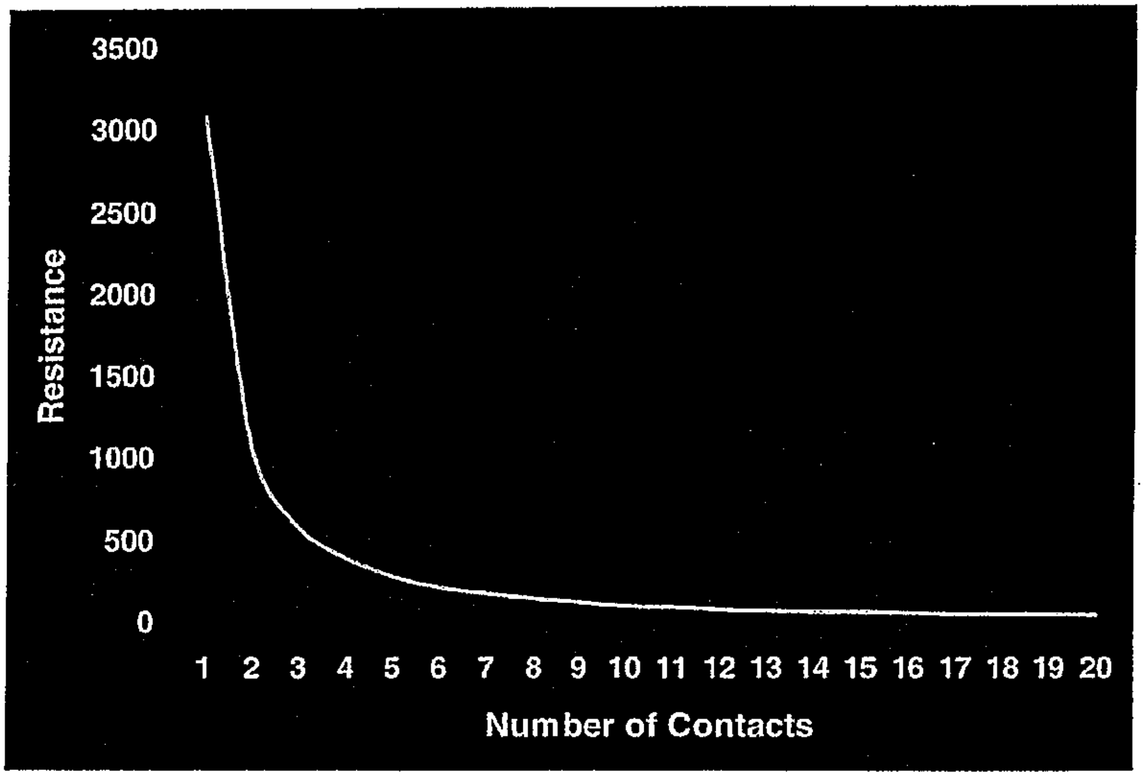
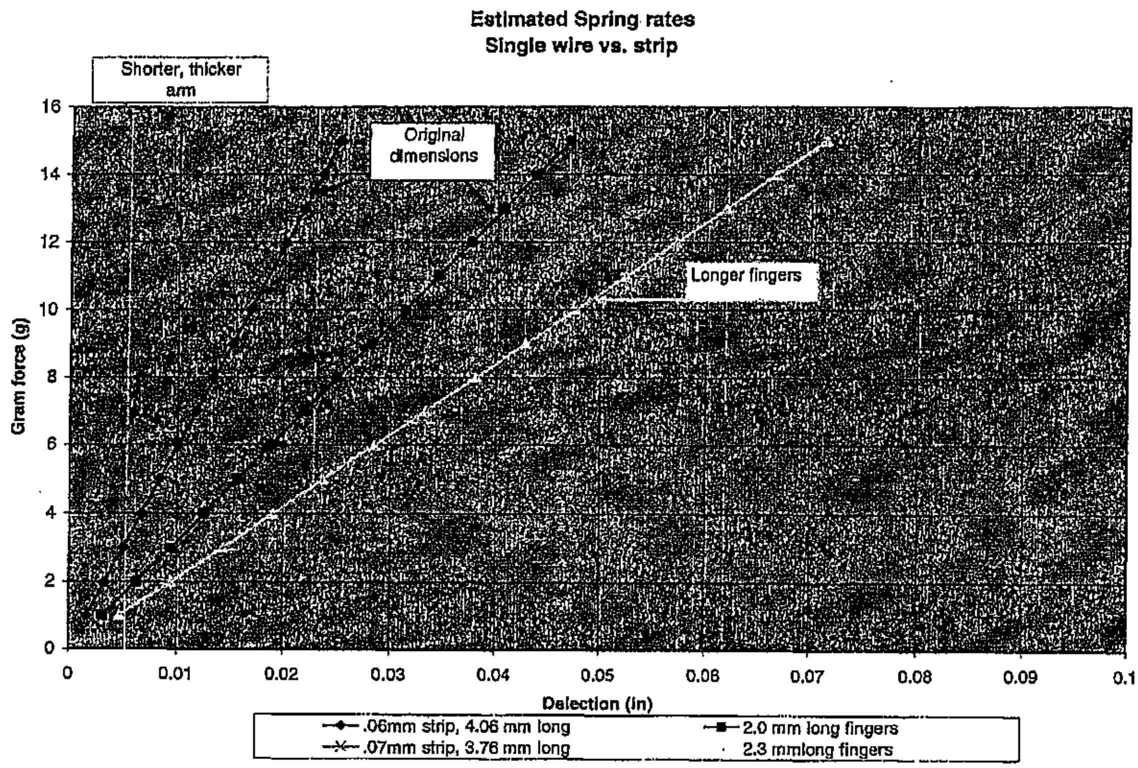


Figure 18
Plot of resultant contact resistance vs the number of points of contact



Calculations assume only a uniform surface film of 2000 milliohms (absolute values will change will resistive strength of the film but the shape of the curve and the position of the "knee" of the curve are independent of the film strength

Figure 19
Idealized spring rate calculations for two simplified cantilever springs that approximate the BeCu spring arm and a single Paliney 7 finger.



Original dimensions shown in dark blue (BeCu spring) and pink (wire)
Yellow line shows effect of increasing wire length by 0.3mm
Light blue line show effect for shortening spring by 0.3mm and increasing thickness to 0.07mm

Appendix-

References: Porosity and Creep corrosion –

1) Abbott, W. A., The effects of test environment on the creep of surface films over Gold Proceedings of the IEEE Holm Conference, 1984, p47-52

2) Williams, D. M. M., The effect of test environment of the creep of base metal surface films over precious metal inlays, Proceedings of IEEE Holm Conference, 1987. p 79-85

3) Chao, J. L. and Gore, R. R., Evaluation of a Mixed Flowing Gas Test, Proceedings of the IEEE Holm Conference, 1991, p 216-228

4) Zhang, J. G., The effect of Environment on Electrical Contact Reliability, Proceedings International Conference on Electrical Contacts 2002, p 205-211

.pdf copies of the references will be placed in an appendix as a separate file on this CD